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Geology and Mineral Resources of Northeastern Franklin County, Pennsylvania

Samuel I. Root

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
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TOPOGRAPHIC AND GEOLOGIC SURVEY
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Geology and Mineral Resources of Northeastern Franklin County, Pennsylvania

by Samuel I. Root
Pennsylvania Geological Survey

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PREFACE

This report concerns the origin, history, and possible use of rocks exposed in northeastern Franklin County.

Rocks exposed range in age from Cambrian to Ordovician (550-450 million years ago). They include a thick series of Cambrian and Ordovician limestones and dolomites (calcium and magnesium carbonates), and the youngest rock which is Ordovician shale. The limestones and dolomites of Cambrian-Ordovician age which cover much of the area are discussed in detail. Data concerning the origin of these rocks and their later folding and faulting are presented. Differences in thickness of the various strata are included. Chemical analyses of the carbonates are presented in a number of graphs. Shales of Ordovician age are exposed in the western part of the area. Data concerning their origin and composition are given. This section of the report will be of particular interest to students of geology and natural history.

A considerable portion of the report is concerned with economic uses of the rocks and minerals in the area. This will be of particular interest in the mineral industries and to professional geologists, urban and rural planners, construction engineers, and conservationists. The mineral history of the area is reviewed and current activities are noted. Specifications for magnesium compounds, chemical grade limestones, coarse aggregate, fine aggregate, dimension stone, and lightweight aggregate and brick are listed. Those rock strata which meet these specifications are discussed. In addition, the ground-water yield of the various rock strata are analyzed and those geologic conditions controlling locations that should be most productive are discussed.

A detailed geologic map shows the distribution of various rock strata and where they are folded and faulted. This map and that part of the text concerning economic and environmental geology are important for purposes of mineral extraction, for various types of construction, and for the location of water wells.

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GEOLOGY AND MINERAL RESOURCES OF NORTHEASTERN FRANKLIN COUNTY, PENNSYLVANIA

by

SAMUEL I. ROOT

ABSTRACT

This report concerns the geology of about 80 square miles in northeastern Franklin County. The area includes lowlands of the Great Valley.

In the Great Valley, marine carbonate rocks of Middle Cambrian to Middle Ordovician age comprise most of the terrain. From oldest to youngest these are the Elbrook Formation, Conococheague Group, Beekmantown Group, St. Paul Group, and Chambersburg Formation. These units probably aggregate about 12,500 feet, predominantly limestone, with minor amounts of dolomite, some shaly limestone, and local thin sandstone beds.

The Martinsburg Formation, a flysch sequence of Middle and Upper Ordovician age shales and graywacke, overlies the carbonates on the west side of the mapped area. Structural complications in this unit permit establishment of only a tentative internal stratigraphy. Thickness cannot be determined. All rocks are structurally part of the South Mountain anticlinorium—Massanutten synclinorium complex. Middle Cambrian to Middle Ordovician carbonates are involved in related folding and faulting. The regional flow cleavage (S_1) and fold pattern geometry are reflected through the entire sequence of rocks indicating that they were deformed as a single unit. All major faults are rectilinear, east-dipping high angle reverse faults. The area is dominated by many parallel asymmetric to overturned folds and parallel faults which can be traced more than 30 miles to the Potomac River, where further extension is limited only by the lack of detailed mapping. Structures cannot be matched across the tear-fault segment of Carbaugh-Marsh Creek fault indicating semi-independent folding across the fault. In the extreme eastern part of the area deformation was of the passive flow type, but over most of the area deformation was of the flexural slip type.

The Martinsburg beds are structurally part of the Massanutten synclinorium. There are insufficient outcrops and marker beds to decipher the structure, but in several large outcrops type and amount of deformation observed differs somewhat from that of the older carbonates.

Several homoaxial stages are recognized in deformation of the area. These are considered to be continuous events, in view of the tectonic history of the region, during a terminal Paleozoic orogeny.

Economic resources include chemical and metallurgical grade limestones that may be exploited locally. Much of the limestone in the area is suitable for class A coarse aggregate. Shales of the Martinsburg have potential use as lightweight aggregate as well as building brick, face brick, and floor tile. Ground-water resources are discussed in terms of potential yield.

INTRODUCTION

This report covers the geology of the northeastern portions of Franklin County. The area concerned in this report includes the Chambersburg and Scotland 7½-minute quadrangles. Emphasis is placed on the Cambro-Ordovician limestones because of their possible economic utility. The younger shales of the Martinsburg Formation, although mapped, are poorly exposed and are less well known.

PHYSIOGRAPHY

Northeastern Franklin county lies principally in the Great Valley section of the Valley and Ridge province and is locally referred to as the Cumberland Valley (Figure 1).

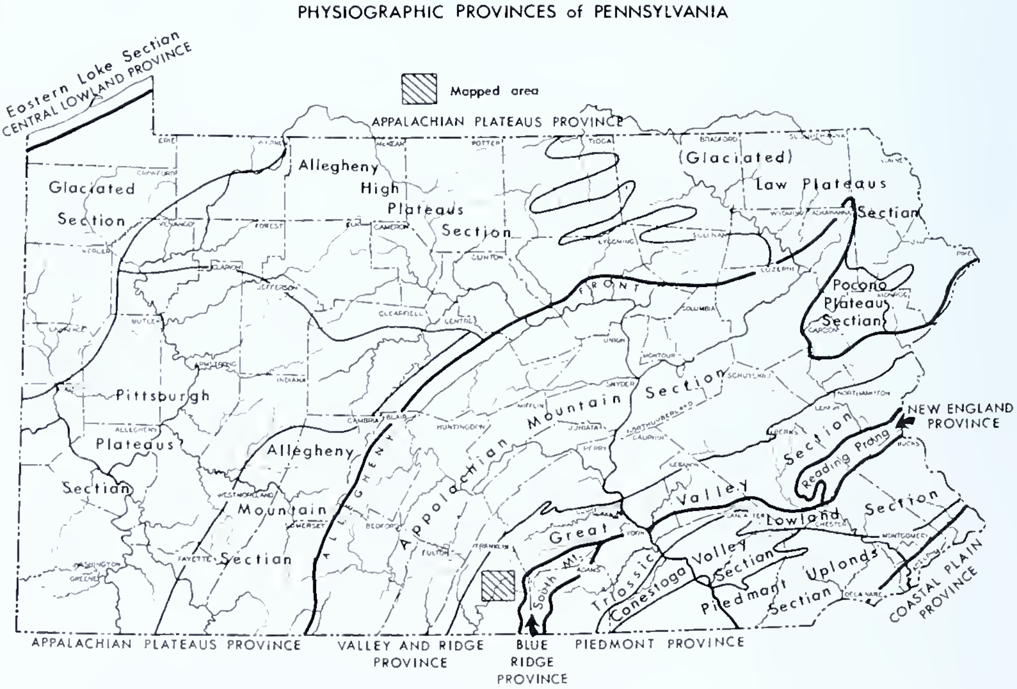

Figure 1. Location of mapped area and physiographic provinces of Pennsylvania.

The Great Valley section near Falling Springs on the east, has elevations of about 850 feet but the surface slopes to the west and elevations at Chambersburg are about 600 feet. Northeast-southwest trending limestone ridges impart a gently rolling aspect to the terrain. Streams are small, usually impermanent, flowing in broad valleys. West of Chambersburg, shale of the Martinsburg Formation floors the valley. This shale area is 100 to 150 feet higher than the adjacent limestones, and is complexly dissected by streams with steep valley walls. The large permanent streams of the Cumberland Valley are restricted to the shale area, generally meandering in small, steep-walled valleys. Conococheague Creek flows close to the limestone-shale contact for a considerable portion of its length.

PREVIOUS WORK

The geology of Franklin County was first investigated in the early 1800's by members of the First Pennsylvania Geologic Survey. A small scale map showing the distribution of the limestone and shale under the name of Auroral limestone and Matinal slate was published by H. D. Rogers in 1858. The Second Pennsylvania Geologic Survey studied the area in some greater detail and a map was published at the scale of 2 miles to 1 inch by R. H. Sanders in 1881 and again by J. P. Lesley in 1885. At the turn of this century the area was mapped by Stose (1909) who subdivided the limestone into many units still in use and recognized the structural complexity; indeed this excellent reconnaissance work is the foundation of all later geologic work in the Cumberland Valley.

Subsequent work in this area has mainly been regional stratigraphic, structural or local economic studies. The most significant work in recent years has been that of Sando (1957, 1958) who subdivided the Beekmantown Group in Maryland into several mappable units. He extended his mapping from Maryland about 1 mile into southernmost Franklin County. Other workers in recent years who have contributed an understanding of the carbonate stratigraphy are Craig (1949), Wilson (1952), Neuman (1951), and Root (1964). The most noteworthy study of structural geology in the Cumberland Valley is that of Cloos (1947, 1951). Cloos' 1951 study also includes some stratigraphic information. A student of Cloos (Fellows, 1943) briefly examined some areas in Franklin County pursuant to a regional structural study of tectonites. The general structure has also been described by Sando (1957), Root (1965), and MacLachlan and Root (1966). The geology and mineral resources of southeastern Franklin County are described in considerable detail by Root (1968). That report should be read as a basis for any geologic studies in this area as it is the most comprehensive and recent study. For information on geology and mineral resources of the older rocks immediately to the east of the mapped area, the work of Fauth (1968) is the most recent and detailed study. The geology on the west has been mapped by Clark (1970).

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Stimulating and fruitful discussions and field trips were made with D. B. MacLachlan, W. J. Sando, P. H. Hoffman, and D. Elliot. Faunal identifications by R. B. Neuman and W. J. Sando proved to be of much help. The preparation of this report was facilitated by many members of the Pennsylvania Geological Survey, especially D. B. MacLachlan.

STRATIGRAPHY

Bedrock exposed in northeastern Franklin County ranges in age from Cambrian to Upper Ordovician (Figure 2), and is all sedimentary. Some surficial deposits occur as alluvium in stream valleys and as terrace gravels on interfluves.

System	Series	Group	FORMATION	DESCRIPTION	THICKNESS (in feet)
ORDOVICIAN	Middle Ordovician		Martinsburg Formation	Black, carbonaceous and fissile shale, weathers buff, with yellow-green to dark-gray fine-grained graywacke beds.	>1,000
			Chambersburg Formation	Dark-gray, cobbly limestone, argillaceous with abundant irregular shaly partings Some metabentonite beds present	600
		St Paul	New Market Row Park	Micritic limestone at top. Granular fossiliferous limestone, black chert, and sparse dolomite in middle Micritic limestone at base	1,000
		Beekmantown	Pinesburg Station Formation	Light-colored, thick-bedded, finely-laminated dolomite	250
	?				
	Lower Ordovician		Rockdale Run Formation	Mostly detrital-skeletal stromatolitic limestone Laminated light gray or buff dolomite interbeds in upper half Some chert in middle and at top At base ±500 feet of pure marbeloid limestone, locally with abundant chert and pink stromatolitic limestone	±3,000
			Stonehenge Formation	Stromatolitic and fine-grained detrital limestones that became predominantly detrital toward the north	550
			Stoufferstown Formation	Coarse-grained detrital limestone with dark-gray siliceous seams, prominent ridge former	220
CAMBRIAN	Upper Cambrian	Conococheague	Shadygrove Formation	Pure light-colored limestones, stromatolitic in part Abundant pinkish limestones and cream colored cherts	750
			Zullinger Formation	Cyclically-bedded stromatolitic-detrital limestone, interbanded limestone and dolomite, interlaminated limestone and dolomite, thin dolomite. Several thin local quartz sand beds.	2,500-3,000
	Middle Cambrian		Elbrook Formation	Light-colored, calcareous shale and argillaceous limestone, blue limestone and dolomite in middle ridge former Pure dark limestone at base	estimated ±3,000

Figure 2. Stratigraphic column in northeastern Franklin County.

The mapped Cambro-Ordovician limestone units about which this report is principally concerned, aggregate to about 13,000 feet in thickness. The thickness of the Martinsburg shale has not yet been determined satisfactorily.

The general disposition of the rocks is simple. There is a progression of successively younger rocks from east to west; from the Blue Ridge anticlinorium to the Massanutten synclinorium.

Limestones are locally fairly well exposed in the Great Valley. The amount of outcrop decreases to the north. The Martinsburg Formation decomposes readily to soil and is poorly exposed except in a few recent road cuts.

Exposures in northern Franklin County are generally less extensive and less frequent than in the southern part of the county. Structural complexity is such that there are few complete stratigraphic sections to be measured and described. On a mapping basis there are few significant lithologic changes from these beds in southern Franklin County. For these reasons much of the lithologic description of the various rock units in this report is adapted from the writer's study of the same units in southeastern Franklin County (Root, 1968).

CAMBRIAN SYSTEM

Elbrook Formation

The Elbrook Formation was named by Stose (1906, p. 209) for a thick series of shaly limestones and calcareous shales. There is a three-fold division within the formation but general lack of outcrop is an impediment to the understanding of this formation.

The distribution of the Elbrook is complex (Plate 1) as it occurs in the core of three large anticlines south of the Carbaugh-Marsh Creek fault. It forms a narrow belt along the eastern border of the mapped area north of this fault; diminishes in width to the north and passes out of the mapped area at Scotland.

The upper part only of the Elbrook Formation is present in the mapped area. The succeeding descriptions of the entire unit is from work immediately to the south (Root, 1968), and is included for the purpose of completeness. The upper and lower portions of the Elbrook form rolling lowlands, but the middle part of the formation forms elongate ridges with relief of about 80 feet.

The basal portion of the Elbrook is composed of 100 feet of pure, dark massive limestone. The contact with the underlying Waynesboro Formation is not exposed but it is probable that the relationship is conformable. The remainder of the lower third of the formation is markedly shaly. It is composed of finely laminated, shaly limestone and calcareous yellow- to green and some reddish shale. These beds readily weather into buff-colored, shaly plates, most of which are leached of their calcareous content and are, therefore, somewhat punky.

Exposed rocks of the middle ridge-forming part of the formation are predominantly bluish-gray limestone with subordinate beds of dolomite. Some limestone beds are composed of stromatolites of the cryptozoon type (Sando, 1957, p. 37). Locally the carbonates appear to be cyclical commencing with a stromatolite- to oolitic limestone bed that contains floating quartz grains and pass into interlaminated limestone and dolomite. The cycles are from 1 to 3 feet thick. Stose (1909, p. 5) states that at this horizon there are some very siliceous, quartzitic limestones which weather to porous slabby sandstone. Apparently the limestone and dolomites and subordinate quartzitic limestones hold up the ridges.

The upper half of the formation, in most of the area, is composed of light-colored calcareous shale and laminated argillaceous limestones. These readily weather into plates of leached shale and underlie valleys relative to the middle ridge-forming part of the Elbrook and the lower ridge-forming part of the Conococheague. There is considerable difficulty in locating the top of the Elbrook Formation in northeastern Franklin County.

Lack of outcrop and structural complexity do not permit an accurate determination of the thickness of the Elbrook Formation. In northern and southern Maryland, Bassler (1919, p. 72) determined a thickness of 3,000 feet. Cloos (1951, p. 44) was unable to determine the thickness of the Elbrook Formation in Washington County, Maryland. In Franklin County, Stose (1909, p. 5) calculated an approximate thickness of 3,000 feet west of Quincy. This figure is accepted for the present, but may be in considerable error.

A sparse, partially preserved trilobite fauna collected by Stose (1909, p. 6) suggests a Middle Cambrian age. The fossils were collected from pure limestones at the base of the formation in a quarry east of Waynesboro.

Conococheague Group

The term Conococheague was first used by Stose (1908, p. 701) in a formational sense for a series of dark-blue banded limestones and subordinate dolomites that are abundant in Franklin County. The formation was elevated to group status by Root (1968, p. 12), with division into a lower Zullinger Formation and an upper Shadygrove Formation.

Rocks of this group form a narrow belt through the eastern part of the mapped area (Plate 1). In the southern half of the mapped area, folding and faulting combine to form a complex pattern of Conococheague distribution. The pattern is more regular in the northern part of the area (Plate 1). The rocks are more resistant than the overlying limestones to the east and form rolling ridges with as much as 150 feet of local relief.

Zullinger Formation

The Zullinger Formation was named by Root (1968, p. 15). It overlies the Elbrook Formation with apparent conformity and seems lithologically gradational with it although nowhere is the contact well exposed. The break in slope and appearance of shaly limestone interbeds marks the top of the Elbrook.

The Zullinger Formation is composed of blue-gray limestone frequently interbedded within dark blue-gray dolomite. This formation is what all previous writers have considered to be typical Conococheague lithology. The Zullinger Formation is well exposed in southeastern Franklin County (Root, 1968). The succeeding description of this unit is based on this work. From observations of various exposures in northeastern Franklin County it is felt that the description of the southern section is equally valid and applicable.

The basal 115 feet is composed of 3- to 4-foot thick beds of interbanded limestone and dolomite with subordinate interbeds of detrital and algal limestone. Above this are 5 feet of sandy dolomite and 87 feet of algal and minor detrital limestones. Algal pipes and clastic filled channels of the type shown by Sando (1957, Pl. 7, Fig. 2) are prominent. This is succeeded by 73 feet of limestones of the algal and detrital types, with some limestones sparsely laminated with dolomite. Five beds of limy sandstone to sandy

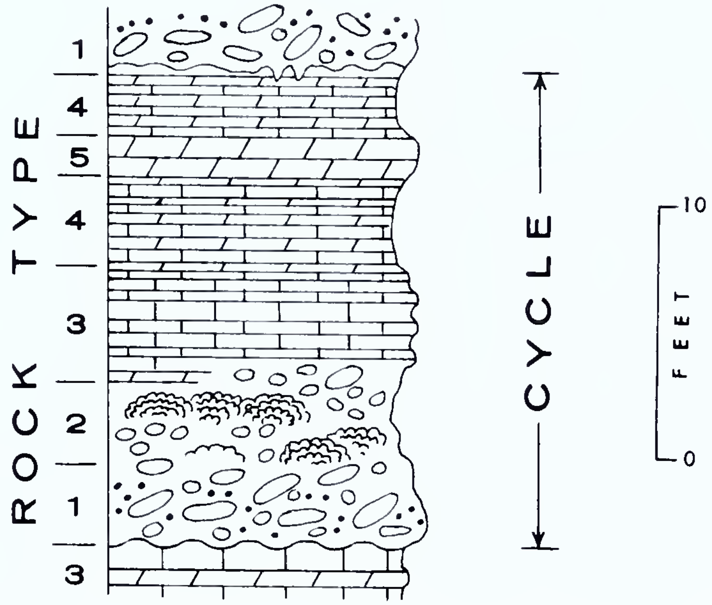


Figure 3. Idealized rock succession within a sedimentary cycle in the Zullinger Formation. Refer to the text for an explanation of the rock types.

limestone occur in the upper half of this unit and probably represent the limited eastward extension of what is the Big Spring Station Member on the western side of the Great Valley. These beds total 280 feet in thickness. There is no outcrop below these beds, and the Conococheague-Elbrook contact is selected where the outcrop ends, which also coincides with the break in slope.

Above this lower portion is an interval 275 feet thick with essentially no outcrop, except for a zone with about 25 feet of limy laminated dolomite, detrital limestone with secondary dolomite patches, and a 1-foot bed of medium-grained, well -sorted, calcareous sandstone.

This is succeeded by the main body of the Zullinger limestones, which is at least 1,550 feet thick. This sequence is composed of cyclically deposited carbonates (Figure 3) which have been described in detail by Root (1964). In the course of measuring this portion of the rock sequence it was apparent that several distinct lithologies, averaging 2 to 5 feet in thickness, are repeated.

Rock type 1 is intraformational limestone conglomerate. In this rock type are included both edgewise and flat-bedded conglomerates. The rock con-

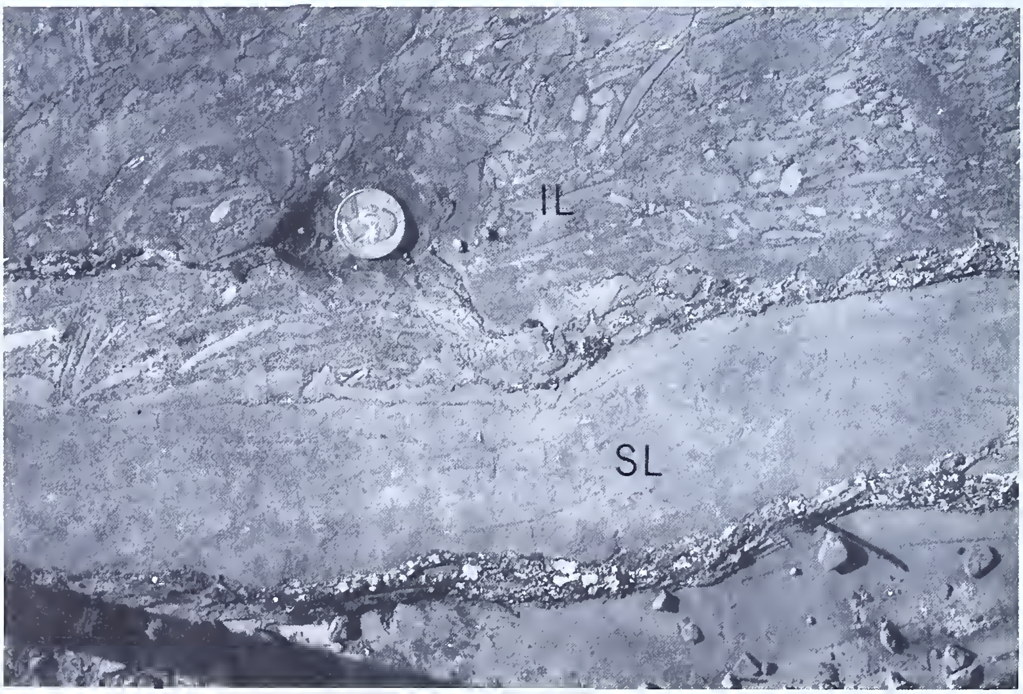


Figure 4. Cyclical limestones of the Zullinger Formation. Intraformational limestone conglomerate (IL) overlies stromatolitic limestone (SL). These correspond to rock types 1 and 2 of Figure 3 and the text.

sists of pebbles of limestone, less frequently dolomite, discoidal in shape with rounded edges, usually ½ to 1 inch long and clearly derived from the underlying or adjacent beds. The clasts are set in a micrite matrix admixed with varied amounts of calcarenitic and oolitic components. This unit is frequently disconformable on the underlying unit (Figure 4).

Rock type 2 is a complex of detrital, stromatolitic, and oolitic limestones. The detrital limestone grains may be of biogenic or of inorganic origin. They seldom range above coarse-sand size and are set in a micrite matrix. The few coquinoidal beds present are included here also.

The stromatolites are mostly of cryptozoon forms, both cabbage head and sheet varieties (Figure 4).

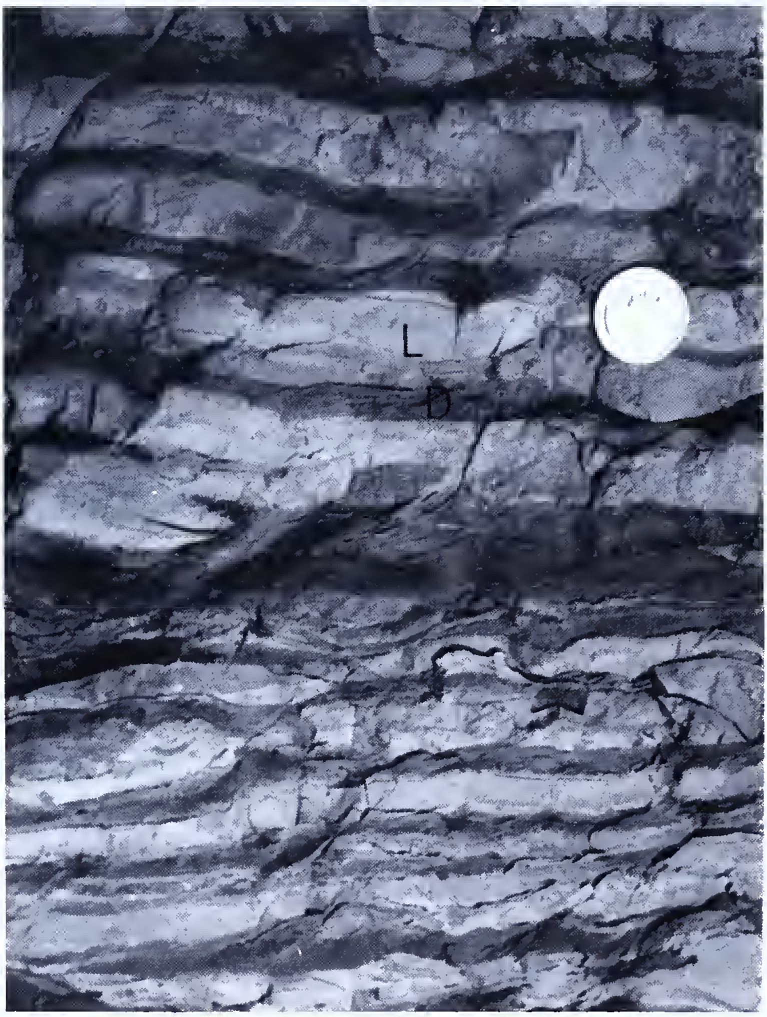


Figure 5. Cyclical carbonates of the Zullinger Formation. These are interbanded limestone (L) and dolomites (D) which comprise rock type 3 of Figure 3 and the text.

Also included in this category are oolitic limestones. The oolites, which show both concentric and radial structure, are well sorted attaining a maximum size of 1 to 2 mm. Tectonic processes have elongated the oolites to some degree although this is not readily apparent in outcrop. They are set in a micrite cement.

The detrital, stromatolitic, and oolitic limestone are all intimately associated. Few beds are composed entirely of a single lithology; an admixture or intercalation of the above lithologies is characteristic of this unit.

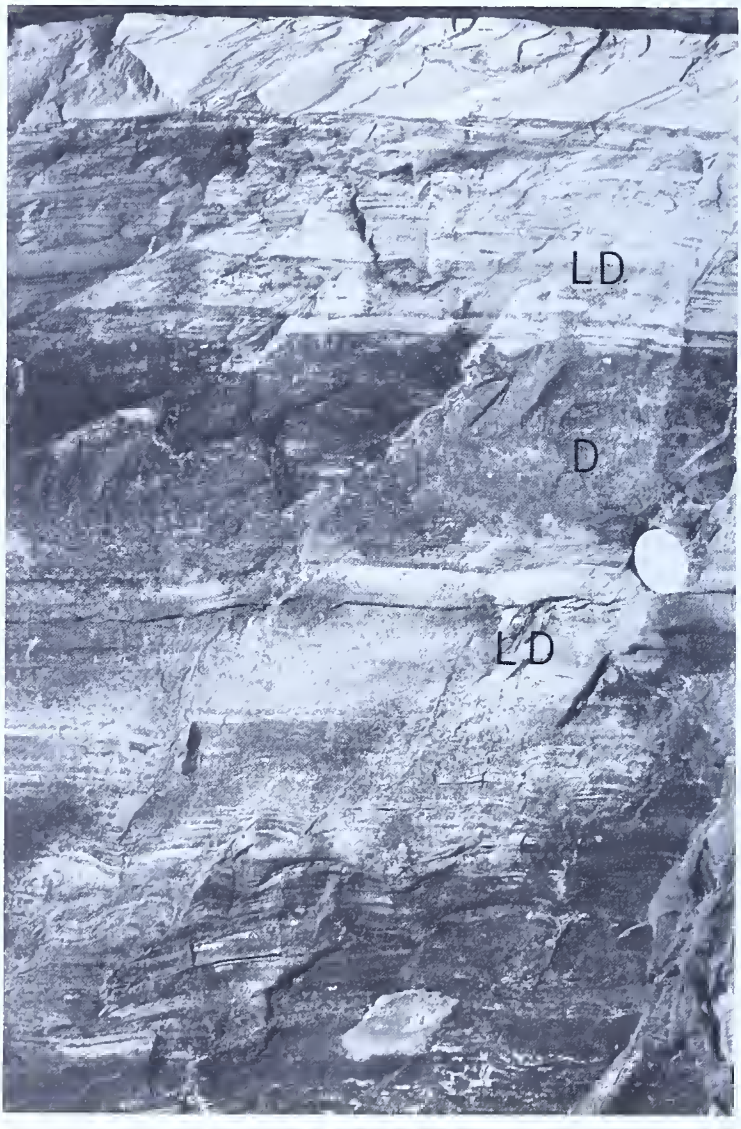


Figure 6. Cyclical carbonates of the Zullinger Formation. Shown here are the interlaminated limestones and dolomites (LD) of rock type 4 which underlie and overlie a thin dolomite bed (D) of rock type S. Refer to Figure 3.

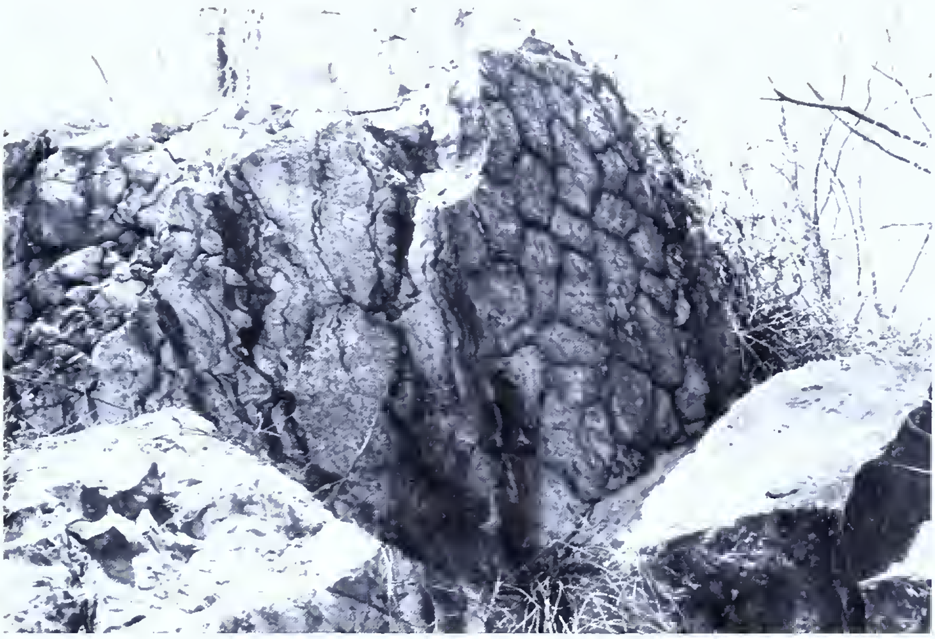


Figure 7. Vertical strata showing underside of mud-cracked algal mat dolomite of rock type 4 in the cyclical beds of the Zullinger Formation.

Rock type 3 consists of limestone interbanded with dolomite. The limestone bands which compose 60 to 70 percent of this rock type are usually $\frac{1}{2}$ to 1 inch thick. Internally the bands may be finely laminated, structureless micritic, or finely clastic. The bands are wavy, imparting a ripple-marked aspect. The silty dolomite is in bands about a quarter of an inch thick and characteristically supports lichen growth. The contrast between the medium-gray limestone and the silty buff dolomite forms a distinctive banding (Figure 5). Occasionally there are intercalations up to 6 inches thick of rock types 1 and 2 with the sequence.

Rock type 4 consists of limestone interlaminated with dolomite. The limestone laminae which usually compose about 60 percent of this rock are 0.1 to 5 mm thick. The laminae are planar and parallel to bedding although gently undulose and cross-bedded laminae are also present. The limestone alternates with dolomite of similar thickness and fabric but which is finely crystalline, buff-colored, silty, and weathers in relief relative to the medium-gray limestone laminae (Figure 6). Frequently well developed polygonal mud cracks (Figure 7) are present in outcrop. The cracks may extend as much as three feet into the interlaminated rock.

Rock type 5 consists of thin dolomite beds that characteristically weather to buff tones in contrast to most of the limestones which weather light to medium gray and are medium to light gray on fresh surfaces. The dolomite is uniformly finely crystalline throughout and harder than adjacent limestones. The dolomite beds are generally structureless but occasionally show some internal laminations due to variations in crystal size (Figure 6).

Silt-size quartz and clay are more abundant in the dolomite than the limestone. Floating sand-size quartz grains occur in some of the dolomites, and several thin sandstone beds composed of medium to coarse grained, rounded, well-sorted quartz grains are intimately associated with the dolomite beds.

The dolomite of this rock type and type 4, because of their texture and structure, aree onsidered as either primary or penecontemporaneous algal-mat dolomite.

This ideal cycle occurs in several places in the Conococheague at Waynecastle Dairy. However, there are numerous places where part of a cycle develops or where the cycle develops but one or more of the rock types is absent.

These rocks are considered to constitute a regressive cycle. The ideal cycle is initiated by high mechanical energy, shallow open marine sediments such as detrital, oolitic, stromatolitic limestones and intraformational conglomerates that are unconformable on the underlying units. Upon shallowing of the water as a consequence of regression low mechanical energy sediments such as interbanded limestone and dolomite form in an intertidal to subtidal environment. With continued regression algal-mat dolomites form in the supratidal environment where they are subject to desiccation. The cycle may then commence to reverse itself as in Figure 3. However, reversal of the cycle should not be construed as a general transgression. Reversal of the cycle is so rare that one may conclude that cyclicity is principally a regressive phenomenon. A single factor of regional extent probably controls this repetition and the simplest mechanism is periods of regression during general basin subsidence. Whether this is due to rhythmic crustal movements or eustatic sea level change is unknown.

In southeastern Franklin County, Root (1968) measured a partial section of the Zullinger that was 2,100 feet thick. As the top of the section was not exposed it was estimated that the formation was about 2,500 feet thick. It is difficult to determine the thickness of the Zullinger in northeastern Franklin County because outcrop is so sparse at the base of the unit, and the contact with the underlying Elbrook Formation is selected topographically where the ridge forming Zullinger carbonates give way to the valley forming Elbrook shales. The ridges south of Timber Hill, on the Shippensburg 7½-quadrangle, (Figure 8) contain a fair amount of outcrop. If the contact is selected at the base of the first ridge below the top of the Zullinger than the Zullinger Formation is about 2,000 feet thick. However, the contact is selected at the base of the second, and more prominent, ridge below the top of the Zullinger and the formation is thus at least several hundred feet thicker. Folding in this interval does not permit accurate calculation. The

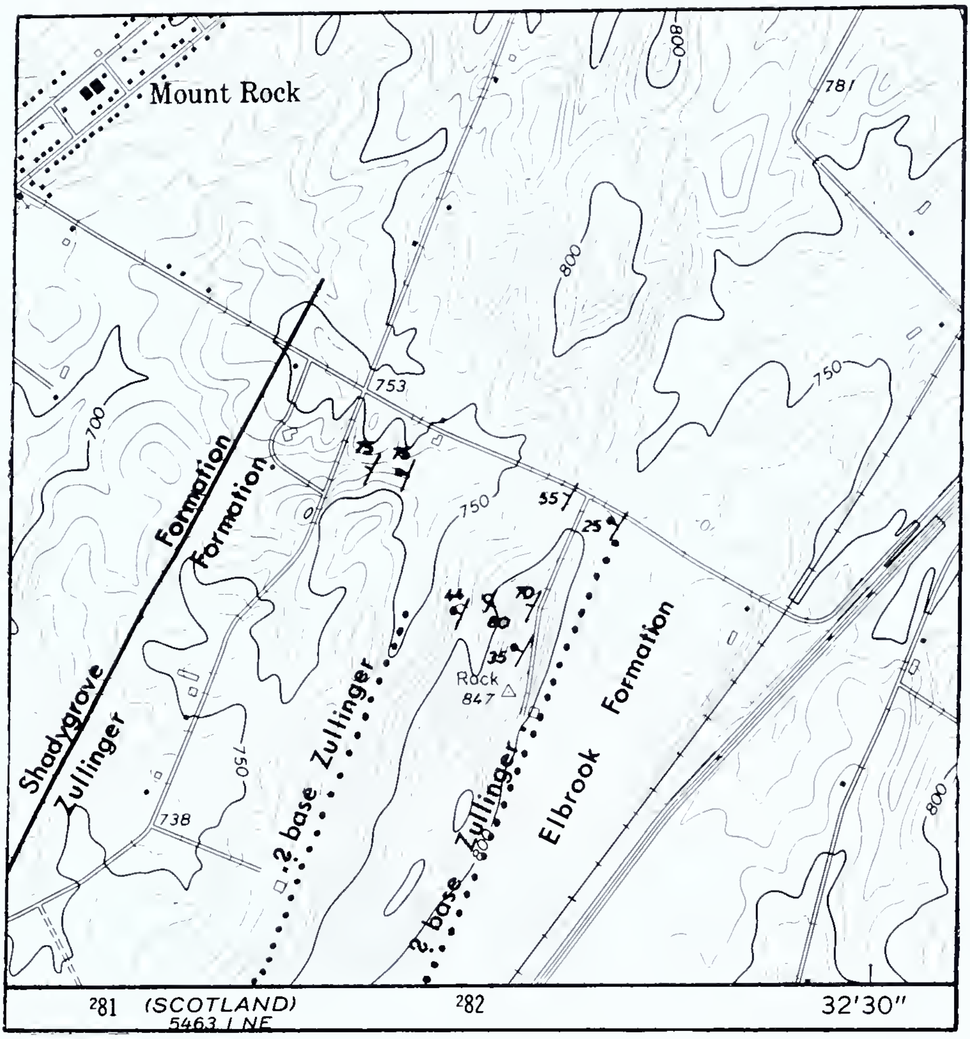


Figure 8. Topographic map showing two possible positions at which the base of the Zullinger Formation may be selected.

intermittent outcrops across these ridges are all carbonates of Zullinger type lithology so that a thickness of 2,500—3,000 feet could be a reasonable estimation. This thickness is in general agreement with the thickness of the Zullinger Formation to the south (Root, 1968).

Trilobites collected by Wilson (1952) indicate that the Zullinger Formation contains late Dresbachian Stage to medial Trempealeauean Stage elements. The Zullinger Formation generally has a sparse fauna; much of it being destroyed by recrystallization of the rock texture or by tectonic deformation.

Shadygrove Formation

The Shadygrove Formation was defined by Root (1968, p. 21) as the relatively pure carbonate beds forming the uppermost part of the Conococheague Group.

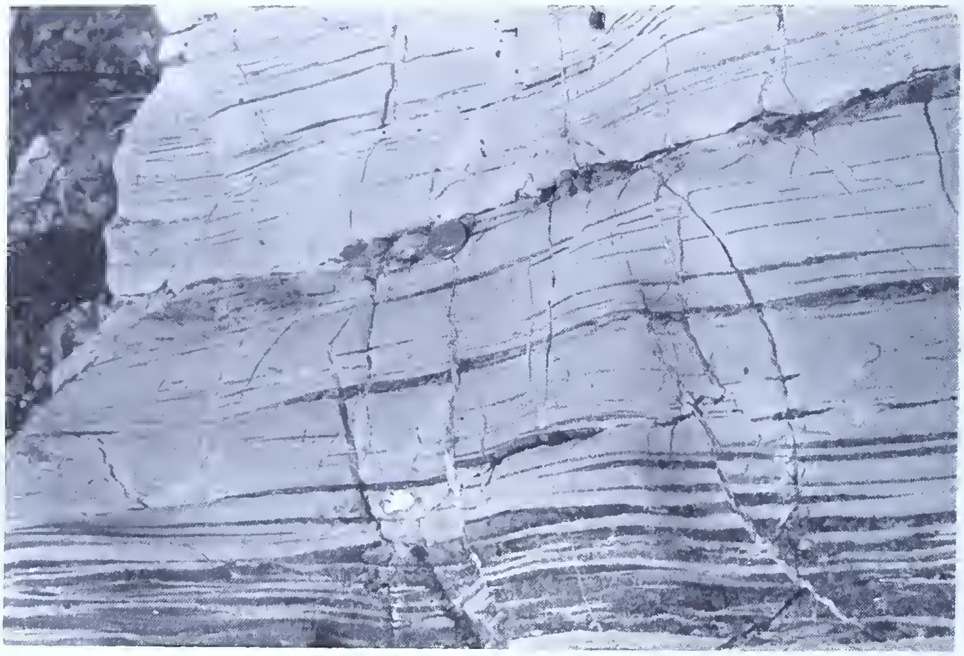


Figure 9. Even bedded, thin banded light blue-gray micritic limestone (?algal origin) of the Shadygrove Formation. Note small chert nodules at coin and darker laminae composed of very fine quartz grains.

The Shadygrove Formation forms a lowland between the ridge-forming limestones of the underlying Zullinger Formation and overlying Beekmantown Group. Blocks of chert are prominent in the soil and in places are piled up against fences. The contact between the Zullinger and Shadygrove Formation is gradational as there are thick beds of light-colored to pink limestone interbedded with the typical limestones and dolomites in the upper part of the Zullinger Formation.

The Shadygrove Formation is well exposed in southeastern Franklin County (Root, 1968). The succeeding description of this unit is based on this work. From various exposures in northeastern Franklin County it is felt that the description of the southern section is equally valid and applicable. At its type section (Root, 1968) Shadygrove beds consist of 3 feet of light blue-gray dense micritic limestone with a pinkish cast and cut by pink calcite veins. This limestone looks similar to the so called ‘vaughanitic’ limestones of the St. Paul Group. A covered interval of 44 feet is present above this. This is succeeded by an interval 130 feet thick, with 60 percent exposure, consisting of light gray weathering micritic algal limestone (Figure 9) and minor medium thick beds of detrital-skeletal limestone with gray dolomite laminae and bands that have a dark cast. Abundant nodules of blocky fracturing, honey-brown to pinkish-brown, coarsely textured chert occur as float. The pure micritic algal limestones have a slight pinkish cast especially when wet. One of the limestone beds also contains abundant floating quartz grains. Above this is an 80-foot covered interval. Overlying this is about 350 feet of intermittent limestone outcrop. The limestone is principally light blue to gray, very finely detrital, and with grayish-buff to yellow-orange seams and laminae of dolomite. Among the limestone types are light gray laminated and structureless algal limestone (Figure 10) with a pinkish cast, interlaminated limestone and dolomite, and intraformational limestone conglomerate.

At the north end of the mapped area, about two miles north and slightly east of Scotland, are abundant exposures of the Shadygrove Formation. Although no stratigraphic section was measured here a thickness for this formation, based on dip and width of outcrop, of about 750 feet was calculated. This compares favorably with the 650 to 780 feet of Shadygrove beds present in southeastern Franklin County (Root, 1968, p. 23).

The Shadygrove Formation includes saukid trilobites of the Trempealeauen Stage. Wilson (1952, p. 315, 316) and Sando (1958, p. 841) collected Trempealeauen faunas from several localities in Franklin County. For convenience, the Cambrian-Ordovician boundary was placed at the

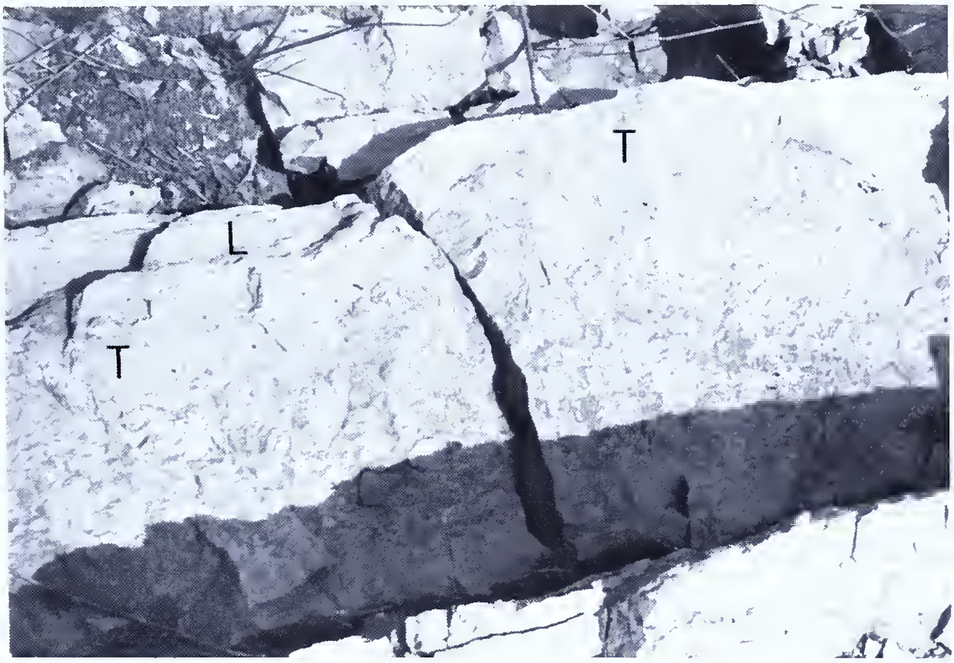


Figure 10. Stromatolites of the Shadygrove Formation. This structure is 6 inches high and shows a thrombolitic (T) or clotted internal texture. Note draping of limestone beds (L) over structure.

base of the Stoufferstown (top of the Shadygrove as used in this report) by Sando (1958, p. 841) although the boundary may be lower by as much as 300 feet.

ORDOVICIAN SYSTEM

Beekmantown Group

The term "Beekmantown" was proposed by Clarke and Schuchert (1899, p. 877) for fossiliferous exposures near Beekmantown, New York and Stose (1909, p. 6) introduced Beekmantown into the Cumberland Valley. He separated the Stonehenge Limestone, a basal member composed of siliceous-banded beds and large edgewise conglomerates, from the upper part of the Beekmantown. In Maryland, adjacent to Franklin County, Sando (1956, 1957), in a detailed study, raised the Beekmantown to group status composed of a basal Stonehenge Limestone, middle Rockdale Run Formation, and upper Pinesburg Station Dolomite. A member, the Stoufferstown, was differentiated at the base of the Stonehenge Formation by Sando (1958) on the basis of work done at Chambersburg. The Stoufferstown was originally the uppermost part of the undivided Conococheague; but, by including it in the Beekmantown, Sando (1958, p. 841) was able to place the Cambrian-Ordovician boundary at the base of the Stoufferstown, without compromising the mappability of the rock units. In southeastern Franklin County, Root (1968) elevated the Stoufferstown to formational rank, and this usage is followed here. The Beekmantown thus consists of four formations, which in ascending order are the Stoufferstown, Stonehenge, Rockdale Run, and Pinesburg Station Formations.

The distribution of the Beekmantown Group is shown on the geologic map (Plate 1). It trends northeast across the eastern part of the area in a belt about 1½ miles wide.

The Beekmantown Group, in the Cumberland Valley, is of Lower Ordovician age. The most recent and detailed work on the Beekmantown age is that of Sando (1957, 1958) and most comments in this section are based on these works. He did not subdivide the Stoufferstown or Stonehenge Formations into formal zones. However the Stonehenge in its entirety comprises the *Bellefontia* zone. The Rockdale Run was divided into four faunal zones which in ascending order are the *Lecanospira* zone, *Archaeoscyphia* zone, *Diparelasma* zone, and *Syntrophopis-Clelandoceros* zone. The Pinesburg Station is devoid of fossils.

Sando (1958) collected and identified an extensive faunal suite from the Beekmantown at Stoufferstown. The location (Appendix, Locality 1) is about two miles due east of the square in Chambersburg. The paleontologic results are presented in the Appendix (Localities 1 and 2). Of special interest is the identification of a large conodont suite and their relation to the standard ostracod-trilobite-cephalopod-gastropod-brachiopod assemblage.

This work should be the standard paleontologic reference for Beekmantown studies in the Cumberland Valley.

The thickness of the Beekmantown Group in Franklin County is similar to that recorded to the south. In West Virginia, Donaldson and Page (1963, p. 167) measured a thickness 4,070 feet. In Maryland, Sando (1957, p. 18) recorded a thickness of 3,600 feet but this did not include the Stoufferstown which he did not recognize at that time. As the Stoufferstown is probably at least 200 feet thick the total Beekmantown thickness should be on the order of 3,800 feet. At Chambersburg, Sando (1958) calculated a partial thickness of about 3,500 feet of Beekmantown strata from a series of combined sections. The top of the Rockdale Run is not exposed and no Pinesburg Station is exposed in these sections. Additional studies by the writer extend Sando's section and indicate that the Beekmantown may be as much as 4,000 feet thick in the Chambersburg area. This is to be discussed below.

Stoufferstown Formation

The Stoufferstown was named by Sando (1958, p. 839) for exposures 1,500 feet north of U.S. Highway 30 at Stoufferstown. As the town of Stoufferstown has merged with Chambersburg, it is best defined as being 12,000 feet east of the center of Chambersburg on U.S. Highway 30.

The Stoufferstown Formation is readily mapped both on the basis of its topographic form and distinctive lithology. It forms a continuous narrow ridge that contrasts with the flat valleys formed by the underlying Shadygrove Formation and the rolling valleys formed by the Stonehenge Formation. The contact with the Shadygrove is sharp but the contact with the Stonehenge is gradationally interbedded.

A good description of the Stoufferstown Formation is given by Sando (1958, p. 840). He refers to this as the coarse-grained lithofacies relative to the Stonehenge, and states:

> The coarse grained lithofacies is composed dominantly of carbonate detritus with particles ranging from clay to cobble size, tabular limestone fragments commonly 2–3 inches in diameter characterize this facies. Many beds are oolitic. The yellowish weathering seams have a high terrigenous quartz content and in places are reinforced by secondary silica so that in many places they weather in sharp relief. Bright-orange weathering patches of dolomite half an inch or less in diameter are a distinctive feature.

The siliceous seams to which Sando refers are important in the recognition of the Stoufferstown; however, they are frequently dark gray to black in color rather than yellowish weathering. They form a distinctive lithology (Figure 11) which underlies the ridges. Where they do not crop out, they form a surficial soil composed of dark colored, hard shaly chips. These seams also occur sparsely near the top of the Zullinger and Stonehenge Formations, but here they are not intimately associated with intraformational conglomerate, especially the edgewise conglomerates so typical of the Stoufferstown Formation.

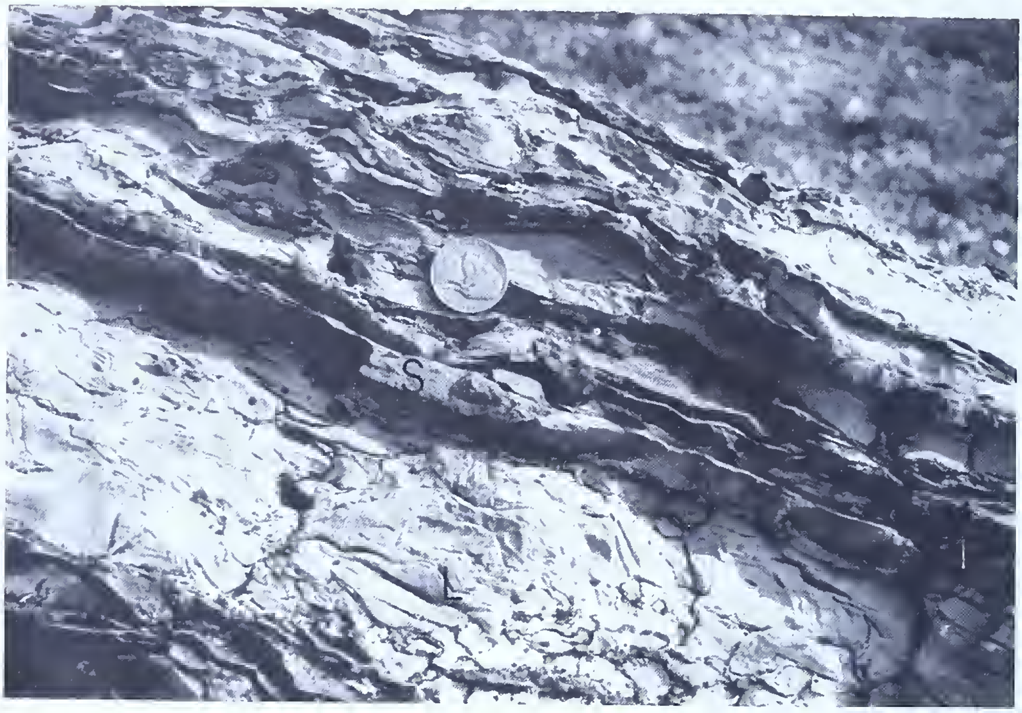


Figure 11. Irregular, dark colored, prominent siliceous seams (S) and edgewise limestone conglomerates (L) typical of the Stoufferstown Formation.

A section of the Stoufferstown Formation was described by Sando (1958) and is presented in the Appendix (Locality 1). The thickness here is about 220 feet. At the extreme north end of the mapped area the Stoufferstown is approximately 200 feet thick. In southeastern Franklin County it is 260 feet thick (Root, 1968, p. 25).

Stonehenge Formation

The term Stonehenge Limestone was used by Stose (1908, p. 703) to designate the basal member of the Beekmantown limestone near the village of Stonehenge at the eastern limits of Chambersburg. Sando (1956, p. 935) raised the Stonehenge to the formation rank and raised the Beekmantown to group rank.

The Stonehenge Formation generally forms low rolling valleys. The upper part of the formation is usually more resistant and underlies a subdued ridge. This ridge, between valley-forming limestones of the lowermost Rockdale Run Formation and the less resistant limestones below it, can be of considerable aid in mapping structures.

In Maryland, Sando (1957, p. 17) informally divided the Stonehenge into a lower fine-grained limestone, thick bedded, with abundant gymnosolenid stromatolites which in many places make up biohermal masses, and an upper member of thin-bedded silty detrital limestone. This informal subdivision cannot be carried into Pennsylvania and was not recognized by Sando (1958, p. 839) at Chambersburg.

From various exposures throughout southeastern Franklin County, Root (1968) constructed a composite lithologic section of the Stonehenge aggregating some 775 feet in thickness. The composite Stonehenge section is divisible into four informal units whose persistence may be limited. At the base of the Stonehenge Formation is a zone about 100 feet thick composed of fine-grained limestone and algal limestone. Above this and forming most of the Stonehenge are about 500 feet of thin-bedded, fine-grained detrital limestones. Overlying this unit is about 75 feet of ridge-forming limestones somewhat similar in appearance to the Stoufferstown Formation. The uppermost unit, about 100 feet thick consists of a 20-foot thick basal horizon of well-developed gymnosolenid stromatolites that make up biohermal masses. Above this is about 80 feet of gray detrital limestone with irregular laminae of argillaceous dolomite. This unit is normally not well exposed, commonly underlying valleys.

Just east of Chambersburg (Sando, 1958) measured several sections of the Stonehenge Formation. His sections are reproduced in this report (Appendix, Localities 1 and 2). Some modifications have been made in these sections to conform with stratigraphic usage of the Pennsylvania Survey. Unit 1, which was termed the Stoufferstown member of the Stonehenge limestone, is, in this report, termed the Stoufferstown Formation. Units 2 to 16, which were termed the upper member of the Stonehenge limestone, are, in this report, termed the Stonehenge Formation. Units 17 and 18, which were included in the Stonehenge, are in this report, for reasons to be discussed subsequently, considered to be part of the Rockdale Run Formation.

According to Sando (1958) the Stonehenge at this section is composed of the following lithology:

> . . . limestone is predominant in the Stonehenge of the Chambersburg area. It is a fine-grained lithofacies composed dominantly of carbonate detritus with component particles ranging from clay to sand in size. Ooliths are uncommon in this facies. The yellowish-weathering seams in these rocks are predominately fine-grained dolomite with subordinate amounts of silt-sized quartz grains; these seams do not commonly stand in sharp relief on a weathered surface.
>
> . . . Approximately the lower half of the Stonehenge is fine-grained mechanical limestone with a few interbeds of algal limestone. In the upper half of this member, the coarse-grained and fine-grained lithofacies of mechanical limestone are interbedded in approximately equal quantities. A few beds or lenses of algal limestone also occur in this part of the member.

Sando (1958) measured a thickness of 692 feet of Stonehenge at his section 2, and concluded that because of poor exposure and faulting the thickness might be closer to 800 feet. This writer sampled a complete section of Stonehenge about 510 feet thick only several hundred feet north of where

Sando's section was measured (Appendix Locality). The reason for this discrepancy is that the author selected the 3-foot bed of laminated dolomite limestone (Sando's unit 17) as the base of the Rockdale Run Formation. This reduces Sando's section 2 to a thickness of about 545 feet; in close agreement with the writer's observed thickness. In southeastern Franklin County this laminated dolomite limestone is a fine mappable unit that serves to define the base of the Rockdale Run, as immediately above this, or within several tens of feet above occur typical light colored, pure, chert-bearing, stromatolitic limestone of the basal Rockdale Run (Root 1968, Appendix, Locality 3). In his section 1, Sando selected a 3-foot bed of laminated dolomitic limestone as the base of the Rockdale Run and in his section 4, he selected a 1-foot bed of laminated dolomitic limestone as the base of the Rockdale Run. In all cases laminated dolomitic limestone is the first bed of this type present in measuring upward through the Stonehenge. It seems reasonable therefore, on a purely lithologic basis, to select unit 17 of Sando's section 2 also as the base of the Rockdale Run Formation and assign a thickness of about 545 feet to the Stonehenge Formation.

Rockdale Run Formation

The Rockdale Run Formation was named by Sando (1956, p. 935) for a series of interbedded limestones and dolomites overlying the Stonehenge Formation near Hicksville, Washington County, Maryland. Although the formation contains considerably less dolomite in Franklin County, it is readily referable to the Rockdale Run of Maryland.

Most of the outcrop belt of the Beekmantown Group is composed of the Rockdale Run Formation. Although it underlies low gently rolling terrain, good outcrops are frequent.

The lower part of the formation forms a distinctive unit in Franklin County, characterized by pinkish marbleoid limestones and chert, and probably should be established as a separate mappable unit.

The section at Antrim Church illustrates the lithology of this lower part of the Rockdale Run Formation in southeastern Franklin County (Root 1968). The base of the Rockdale Run was picked at a 4-foot thick laminated dolomite with subordinate interlaminations of limestones. This is succeeded by 36 feet of limestone, micritic in the lower part but detrital in the upper part. Above this are the beds that make this lower part so distinctive. They commence with 32 feet of pure micritic cryptozoon stromatolitic limestone with the form of laterally linked hemispheroids (Logan, and others, 1964). Although these limestones are medium light gray the stromatolitic form is outlined by orange dolomitic laminae. Some 3-inch long creamy chert nodules are present at the top of the horizon. Above this is a bed 1 foot thick composed of pink-orange stromatolitic limestones with a marblelike texture and 8-inch long nodules of blocky, creamy to light-honey colored chert. This is succeeded by 350 feet of intermittently exposed pure micritic limestones that are probably stromatolitic in part. Although the limestones are medium gray, at about 6 horizons they are pink or have a pinkish cast when wet. In places they may be confused with the "vaughanites" of the St. Paul Group. Towards the top are several beds of limy dolomite.

The base of this unit may be difficult to select if the dolomite bed is absent but this will result in an error of only about 35 feet in stratigraphic position as the overlying pink micritic limestone and chert are so distinctive. The cherts form a ridge and it is possible to walk along this bed over distances of several thousand feet, although the unit as a whole is poorly exposed. In Maryland Sando (1957) also selected the base of the Rockdale Run on the presence of chert and dolomite. The chert at this horizon is distinctive. It forms nodules to several inches in diameter that break with a smooth blocky fracture and are typically light honey brown. They show up strikingly as float in cultivated fields.

It was not possible to determine the thickness of the lower Rockdale Run unit. The section measured at Antrim Church passes westward into a syncline and then is covered. The total thickness of pure micritic limestones at this section is 420 feet and although the contact with the more typical limestones of the Rockdale Run was not observed, it is probably not more than 600 feet thick.

This unit has also been exposed in a recent stripping operation at the New Franklin Quarries. About 300 feet of the unit have been exposed by stripping, however, the top of the unit has not been exposed so that this is a minimal thickness value. In the lower 60 feet of this unit are prominent pink stromatolites bearing honey-brown chert nodules (Figures 12 and 13). Several clay bands as much as 2 feet thick also occur in this interval and are the first occurrence of such a lithology in this area. It has not been determined if they are actually weathered clay shales or highly weathered argillaceous limestone. Some layers of coarse-grained quartz sand also are present. Above this are massive, generally homogenous micritic limestones, possibly of algal origin, that appear to be quite pure. They resemble the "vaughanites" of the St. Paul Group. Locally honey-brown chert occurs both as isolated nodules or concentrated along bedding surfaces (Figure 14).

Beds of the Rockdale Run Formation overlying the algal micrite-chert basal beds are more typical of the Rockdale Run beds described by previous writers in this area. Detrital and stromatolitic limestones are abundant in the lower two-thirds with dolomitic limestones and dolomites becoming interbedded with these lithologies in the upper half. One of the most typical lithologies is a fine-grained micritic-detrital limestone with numerous irregular laminae of dolomite (Figure 15). The aspect of the coarser grained detrital limestones is shown in Figure 16, and seldom do the clasts exceed the dimensions of those in the photograph. The lithology of the dolomitic limestones and dolomites is shown in Figure 17. The thick dolomite beds are finely laminated and gashed by solution in fractures on the weathered surface.

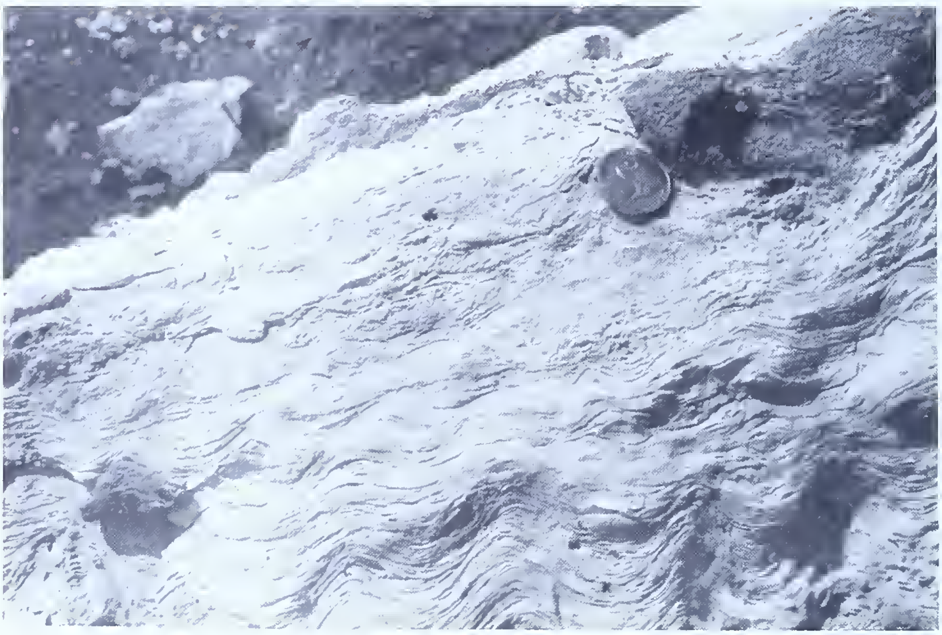


Figure 12. Cross section through pinkish stromatolitic limestone about 50 feet above the base of the Rockdale Run Formation. Note chert nodules at coin.

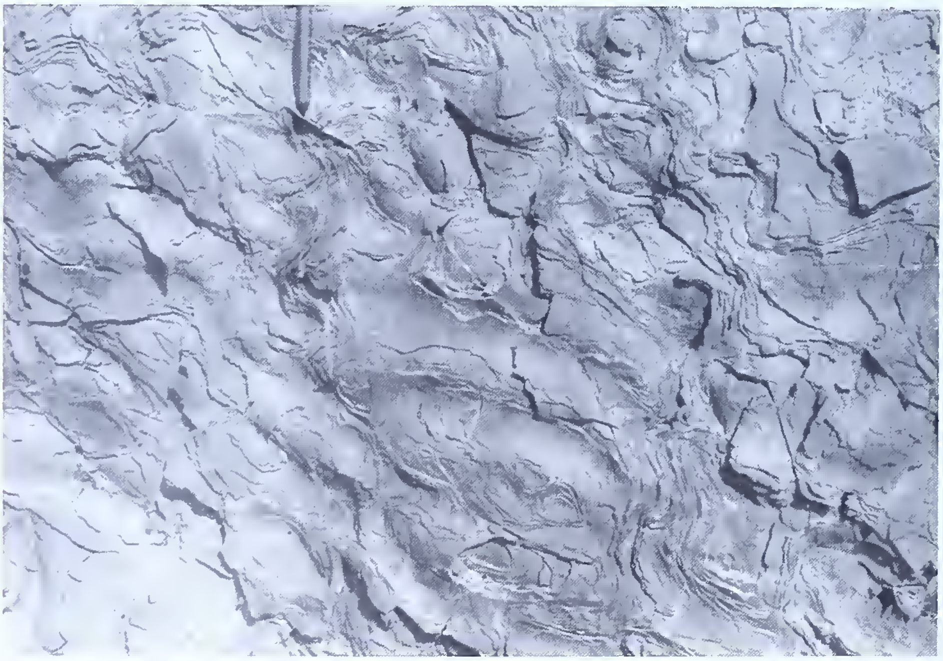


Figure 13. Bedding plane showing upper surface of stromatolitic limestone in Figure 12. Note pencil for scale.

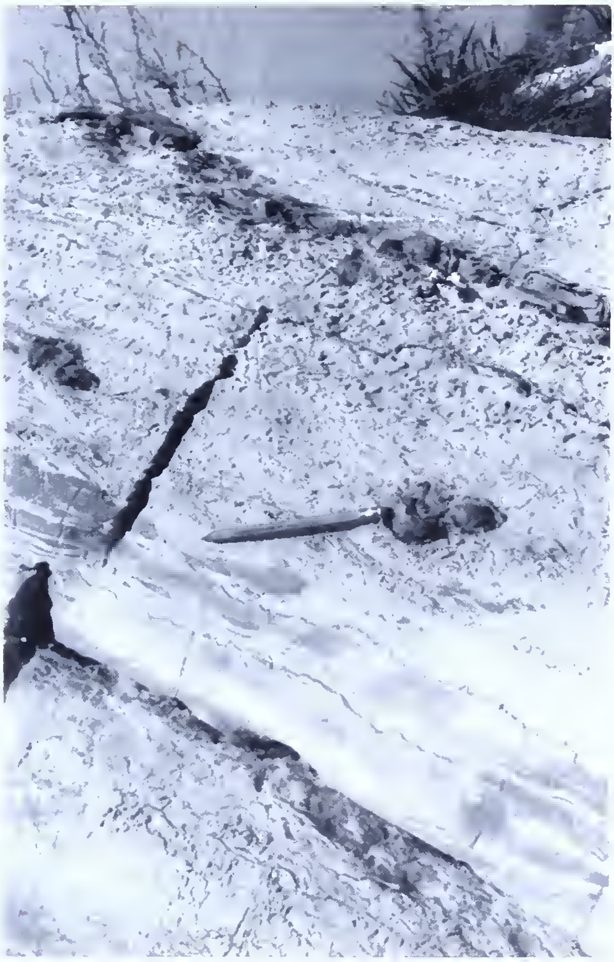


Figure 14. Light colored micritic limestones about 140 feet above the base of the Rockdale Run Formation. Note honey-brown chert below pencil.

The Rockdale Run section measured by Sando (1958) near Chambersburg is included in the Appendix (Localities 1 and 2) of this report for the sake of a detailed description. Sando measured about 2550 feet of Rockdale Run beds above the Stonehenge Formation.

At the stratigraphic position that corresponds to the top of the Rockdale Run Formation both Stose (1909, p. 7) and Sando (1957) report an occurrence of light colored chert that has been called the rosette chert because of its shape. This chert occurs generally as small isolated nodules 1 to 2 inches in diameter and is generally white to cream-colored (Figure 18). Characteristically, it weathers to angular white chips and thus is distinct from the chert at the base of the Rockdale Run which weathers to large rounded honey-brown cobbles with a blocky fracture.

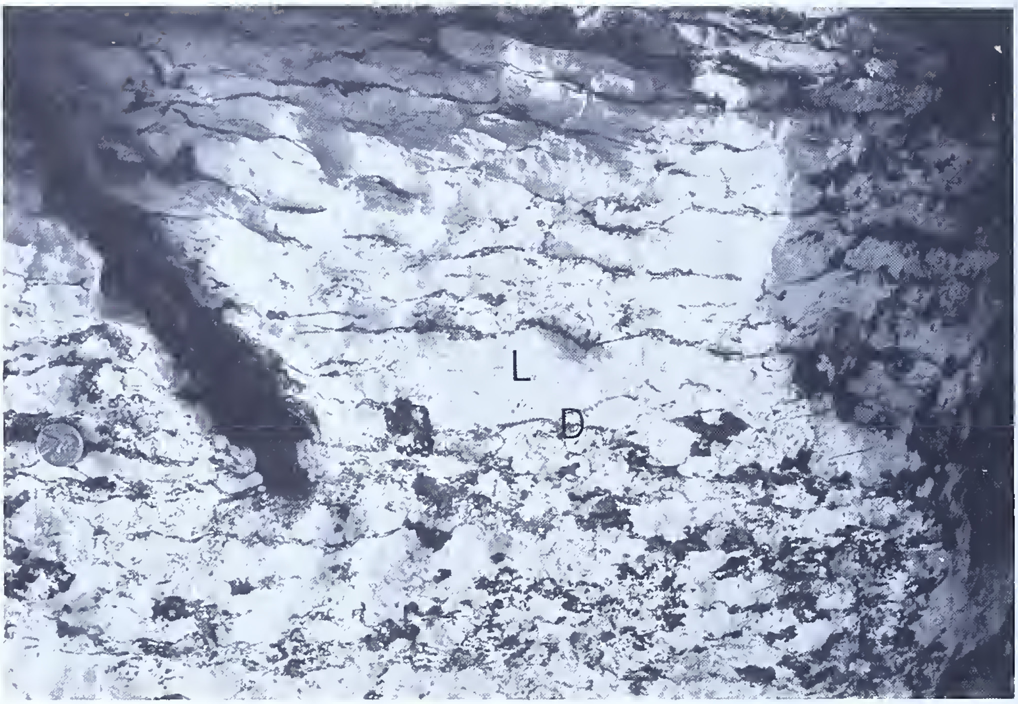


Figure 15. Fine-grained detrital limestones (L) with crinkly dolomite laminae (D) typical of the Rockdale Run Formation. Note preferential lichen growth on dolomite laminae.

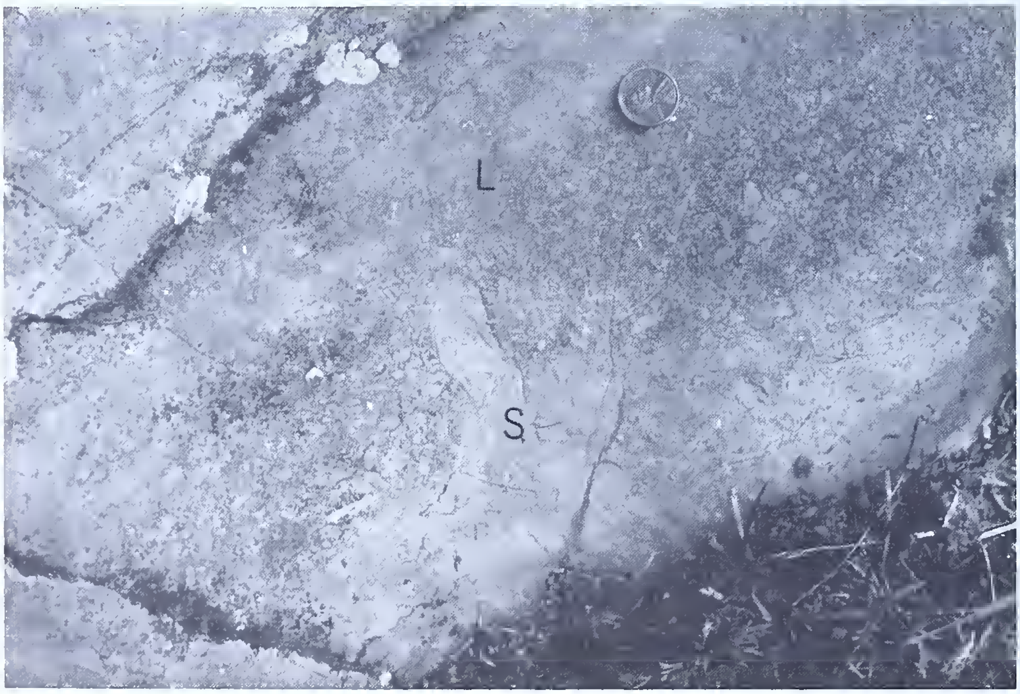


Figure 16. Coarse-grained to finely conglomeratic detrital limestone (L) and a small stromatolite (S) in growth position, typical of the Rockdale Run Formation.

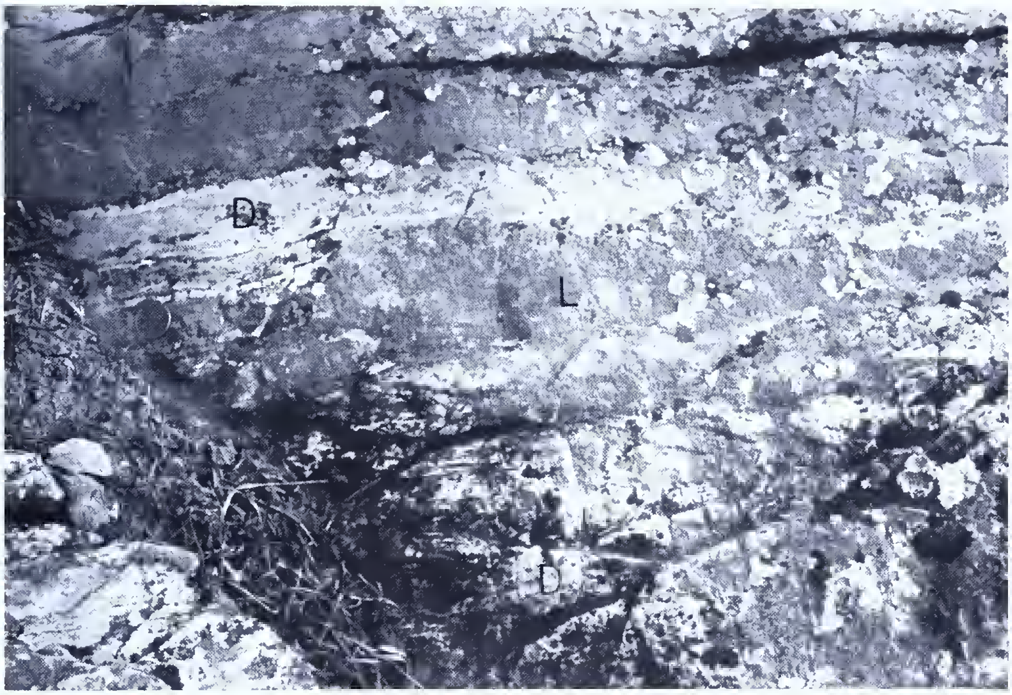


Figure 17. Interbedded dark gray limestone (L) and light-gray dolomite and limy dolomite (D) typical of the Rockdale Run Formation. Note mud-cracked dolomite band above coin and preferential growth of lichen on the dolomite laminae.

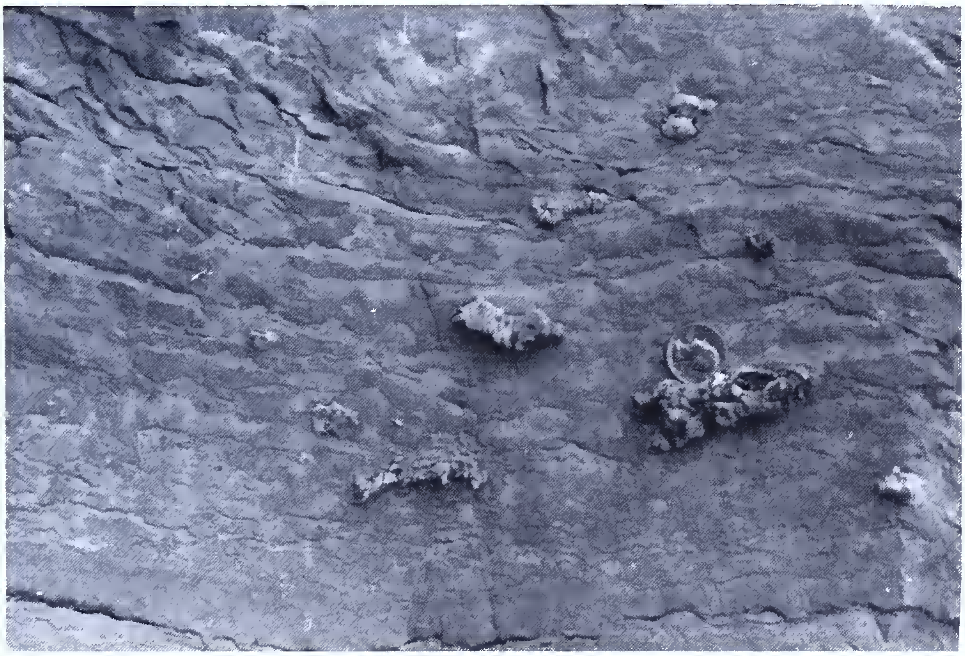


Figure 18. Burrowed or bioturbated limestone with white chert nodule at coin. Uppermost Rockdale Run Formation at Harrison School section.

This uppermost portion of the Rockdale Run also contains a considerable number of dolomite beds and some beds of pure micritic limestone as well as the typical beds of micritic-detrital limestone. As a whole it is distinctive from the underlying beds that constitute the bulk of the Rockdale Run. A stratigraphic section of the upper Rockdale Run Formation, Pinesburg Station Formation, and lowermost part of the St. Paul Group was measured about 2 miles south of Chambersburg. This detailed description is in the Appendix (Locality 3) and shown graphically on Plate 2.

Some 500 feet of chert and dolomite bearing uppermost Rockdale Run are included in this section. As this lithologic assemblage was not observed in the 2,550 feet of Rockdale Run measured by Sando, it appears that these beds are stratigraphically above the 2,500 feet of Rockdale Run limestones. Therefore the Rockdale Run is at least 3,000 feet thick in the Chambersburg area.

On the basis of the preceding discussions it is possible to recognize the following informal threefold division of the Rockdale Run Formation. A basal unit, probably 400 to 600 feet thick, composed principally of stromatolitic limestone and pure light colored limestones that all locally may show a pinkish color, and contain large nodules of honey-brown, blocky fracturing chert. A middle unit, about 2,000 feet thick, composed principally of micritic

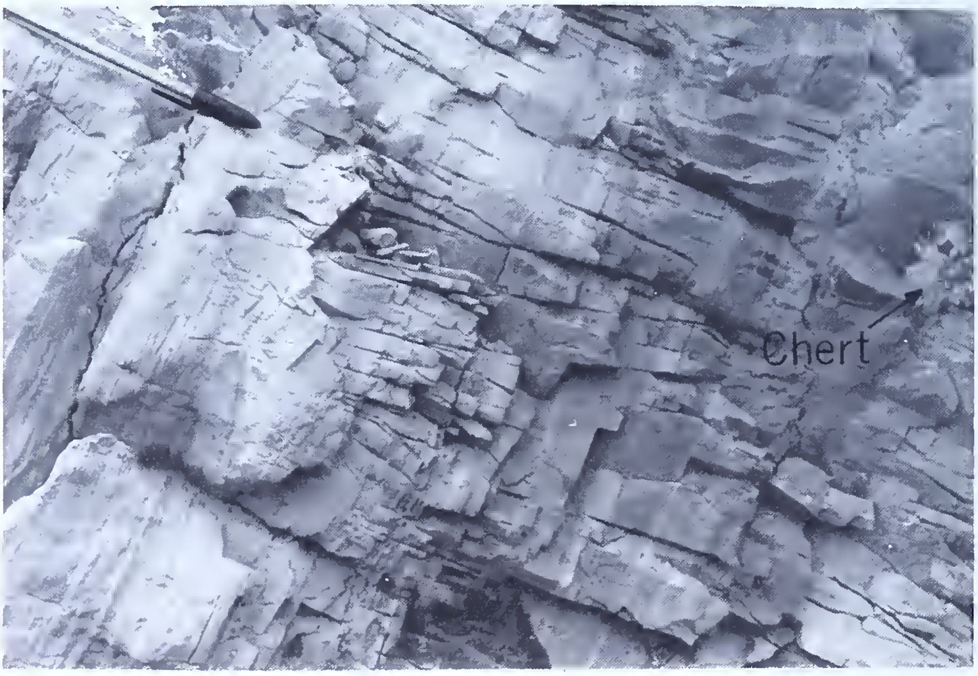


Figure 19. Dolomite of the Pinesburg Station Formation. Note fine banding and laminations and closely spaced fractures. Arrow points to white chert nodule. Harrison School Section. Stratigraphic top to left of photo.

detrital and subordinate stromatolitic limestones. An upper unit, about 500 feet thick composed of limestones and a significant number of dolomite beds, both of which contain small white chert nodules frequently with a "rosette" structure.

Pinesburg Station Formation

The name Pinesburg Station dolomite was applied by Sando (1956, p. 936) to a succession of dolomites overlying the Rockdale Run Formation and underlying limestones of the St. Paul Group. Root (1968) used the term Pinesburg Station Formation for these rocks in southeastern Franklin County.

The dolomites in the Pinesburg Station Formation weather a characteristic medium-gray and are structureless to locally planar laminated. Frequently, there is a lamination or banding due to subtle variation in color tones on the weathered surface (Figure 19). Small white rosette chert nodules, identical to those in the underlying Rockdale Run beds and sparse, dark-gray to black chert masses as much as three feet in largest dimension also are present. Some limestones are included in the uppermost part of the formation. A detailed description of this unit is presented in the Appendix (Locality 3) and Plate 2.

The formation grades down into the Rockdale Run Formation and grades up into the St. Paul Group so that selection of the formational boundaries is difficult. In Maryland Sando (1965, 1958) selected the base at the highest occurrence of limestone in the Rockdale Run and the top at the first occurrence of limestone above the main dolomite body so that the formation is wholly composed of dolomite. At Worleytown in southeastern Franklin County a partially exposed section of the Pinesburg Station Formation is about 260 feet thick, and probably is composed wholly of dolomite. In the only complete section in this report area near Harrison School, (Locality 3, Appendix, and Plate 2), there are about 160 feet of beds composed principally of dolomite. Above this are about 100 feet of limestone and subordinate chert-bearing dolomites at the top of which is about 8 feet (unit 126, Appendix, Locality 3) of dolomitic shale. This hundred feet of strata are included with the Pinesburg Station Formation so that the total thickness of the formation is about 255 feet—comparable to the thickness at Worleytown. Although the inclusion of limestone beds into the Pinesburg Station formation does not meet the strict definition of this formation (Sando, 1956) it is felt that the associated cherty dolomites and especially the dolomitic shales reflect depositional conditions more related to the Pinesburg Station sediments than the St. Paul sediments. An alternative would be to confound the stratigraphic nomenclature even more and assign a new formational name to these 100 feet of strata and include them with either the Beekmantown or St. Paul Groups.

Although the Pinesburg Station Formation is shown as present in a series of complex folds between Chambersburg and Green Village (Plate 1), it has not actually been observed here. The structural interpretation selected for this local area is that of a series of folds, rather than faults, so that the Pinesburg Station should be present somewhere between the exposed Rockdale Run and St. Paul beds if the structural model is valid. Exposure generally is poor in this area; and, as the Pinesburg Station Formation does not have any significant topographic expression or tendency to outcrop well throughout the county, it may well be present here.

St. Paul Group

Limestones of the St. Paul Group are the most important units in the Great Valley because of their economic importance in West Virginia and Virginia. Neuman (1951) defined this group rejecting the old name of Stones River. He divided the St. Paul Group into a lower Row Park and an upper New Market Formation.

For mapping purposes the St. Paul Group cannot be readily divided into its component formations or the proposed members. Although the St. Paul has unique lithologies that are readily distinguished from the other carbonate formations, in limited outcrop there is no single St. Paul lithology so restricted that it can indicate its stratigraphic position. Also major lithofacies changes, that are imperfectly understood, occur within the St. Paul. As Neuman (1951, p. 292) states, faunal criteria are conclusive in differentiating the two formations. For these reasons the St. Paul Group is not differentiated on the geologic map (Plate 1).

Unfortunately, because of poor outcrop and complex folding and faulting there is nowhere in this report area a complete section of the St. Paul Group. A partial section of the upper several hundred feet of the unit was measured (Appendix, Locality 4). However, this is not adequate for what is an economically important unit in this region. Therefore, a complete section from Marion in southeastern Franklin County (Root, 1968) is included to convey the general sense of the lithologies of the unit.

At Marion the Pinesburg Station Formation consists of interbedded dolomites and limestones some of which are dove-colored micritic limestone. These grade upward into beds of pure dove-colored micritic limestone at the base of the St. Paul, which is arbitrarily selected above the highest dolomite. The micritic limestones are from 50 to 120 feet thick; some with birdseye structure that results from clear sparry calcite infilling of fossil and other undetermined voids. Above this is a dark gray, thick-bedded limestone composed of fine-grained skeletal and detrital material, with irregular argillaceous laminae. Locally this zone contains spectacular shells of *Maclurite magnus*, *Girvanella* and black chert nodules. Thickness of this unit ranges from 70 to 220 feet and it is the most readily traceable unit in the group. This is overlain by a zone of dark gray, granular, thick-bedded limestone with argillaceous laminae and some chert. Thickness ranges from 170 to 205 feet.

The Row Park which is composed of the units just described ranges from about 300 feet to 550 feet in thickness.

The base of the New Market can be selected readily at Marion because of the abundant black chert nodules which are present in the thin-bedded, dark-gray, fine-grained, striped to banded limestones. This unit attains a maximum thickness of 80 feet at Marion. Overlying the cherty horizon is a sequence of fine-grained, dark-gray limestone and minor bluish micritic limestone. At Marion nine dolomitic beds are present as part of a cyclical limestone-dolomite alternation. The cycle is initiated by algal stromatolites that are space-laterally linked hemispheroids with some close linked hemispheroids as a microstructure in the constituent laminae (Logan, and others, 1964, p. 74). These obvious algal stromatolite beds pass laterally and vertically in structureless blue-gray limestone micrites that may also be of algal origin. Wolf (1965) discusses the process of "grain diminution" of algal colonies to structureless micrite. This effect may be of importance here and in the origin of the pure micrites of the Zullinger Formation and micrite-chert zone at the base of the Rockdale Run Formation all of which have important algal-stromatolite constituents. The upper surfaces of these structureless beds show mud cracks, the spaces of which are infilled by yellow-gray dolomite detritus (?). Above these are beds of medium yellow gray, finely laminated dolomite the upper surface of which is sharp and overlain by another cycle of algal stromatolites. The limestone beds are 3 to 4 feet thick and the dolomite beds 1 to 2 feet thick. Two such cycles are well exposed at Marion and appear to represent normal shallow marine limestone deposition alternating with desiccation and deposition of supratidal (?) dolomite. As many as nine cycles may be present in this interval. The uppermost part of the St. Paul consists of a series of dove-colored micritic limestones. At the very top these are interbedded, through an interval of perhaps 20 feet, with the cobbly limestones somewhat similar to the cobbly limestone of the Chambersburg Formation.

The section measured just south of Chambersburg (Appendix, Locality 4) includes about 800 feet of St. Paul below the Chambersburg and the base is not exposed. About 340 feet below the top of the St. Paul is a zone of faulting (Unit 66) that probably duplicates a considerable amount of the uppermost St. Paul. This duplication is based on the absence here of a chert zone that occurs about 500 feet below the top of the nearby section at Marion (Root, 1968) and should occur in this relatively thick, but incomplete St. Paul section. It may be that the chert zone is local but its occurrence about 2 miles to the north seems to indicate that it is widespread and should occur within the interval measured in this section. Therefore it seems that the section includes repeated upper St. Paul.

The major lithologies in this measured section (Appendix, Locality 4) include some beds of pure structureless micritic limestone, and stromatolitic

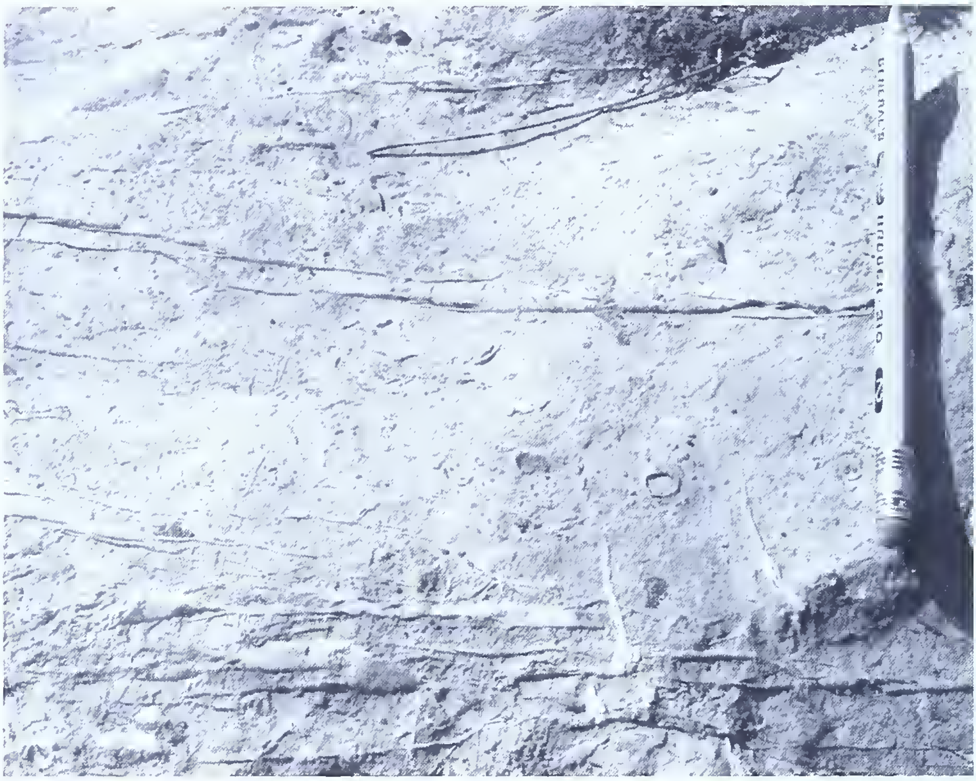


Figure 20. Detrital skeletal limestone from the upper part of the St. Paul Group, south of Chambersburg.

limestone but principally beds of skeletal and fine- to very-fine detrital micritic limestone (Figure 20) or semi-planar interbanded micritic to detrital micritic blue-gray limestone and thinner light gray dolomitic limestone that forms a distinctive "banded" rock (Figure 21).

From scattered exposures throughout the area it appears that the St. Paul Group lithologic sequence is, in general terms, the same as that described previously at the nearby Marion section. It is assumed that the thickness of the St. Paul Group is 1000 feet—the same as that measured at the Marion section. This seems a reasonable value as near Carlisle it is about 700 feet thick (Prouty, 1960).

The following brachiopods were collected about 6500 feet south of the square in Chambersburg from ledges just east of U.S. Highway 11. They were identified by R. B. Neuman of the U.S. Geological Survey.

Camerella? sp.
Hesperorthis sp.
Leptellina? sp.
Mimella sp.
Valcourea sp.

Also undetermined bryozoans, gastropods, trilobites, and ostracodes. Another collection, also identified by R. B. Neuman, about 1200 feet southwest along strike from the previous collection yielded the following brachiopods:

Glyptorthis sp.
Hesperorthis biconvexa Cooper
Protozyga sp.
Skenidioides sp.
Valcourea sp.

These collections were from the thin bedded, nodular chert bearing, slightly cobbly limestones (Figure 22) that form the middle of the St. Paul Group. The fossils are unique in that they are completely silicified and show excellent detail. Locally they have weathered out of the rock and litter the area of outcrop.

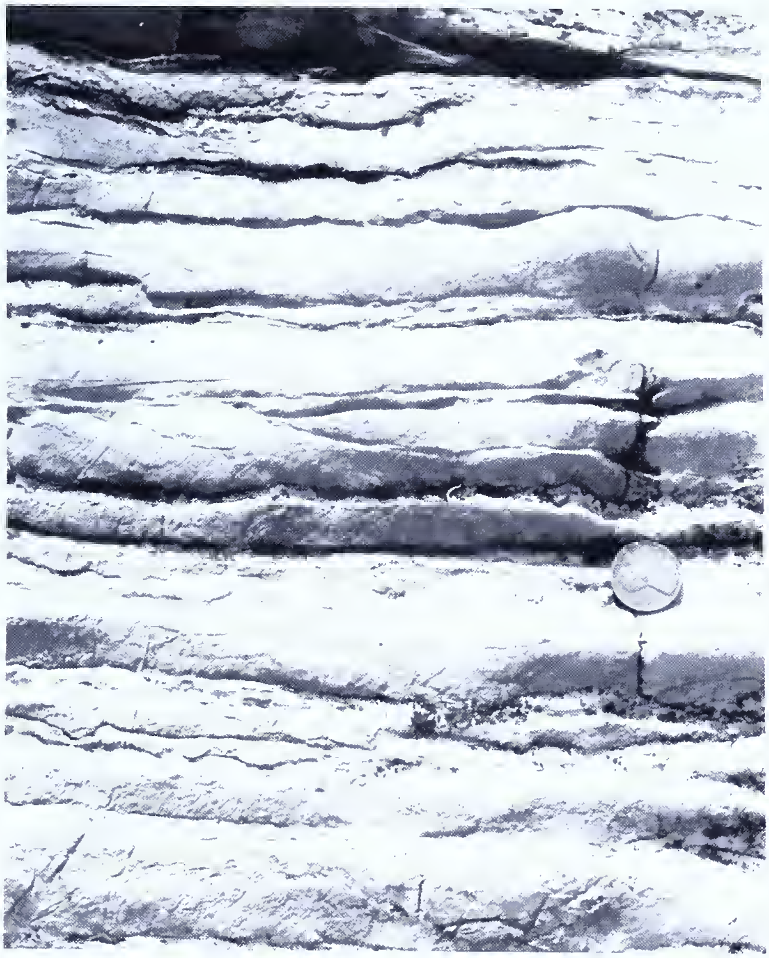


Figure 21. Distinctive banded St. Paul limestones composed of bands of micritic to very-finely detrital blue-gray limestones, interbanded with light-gray dolomitic limestones. Coin rests on latter.

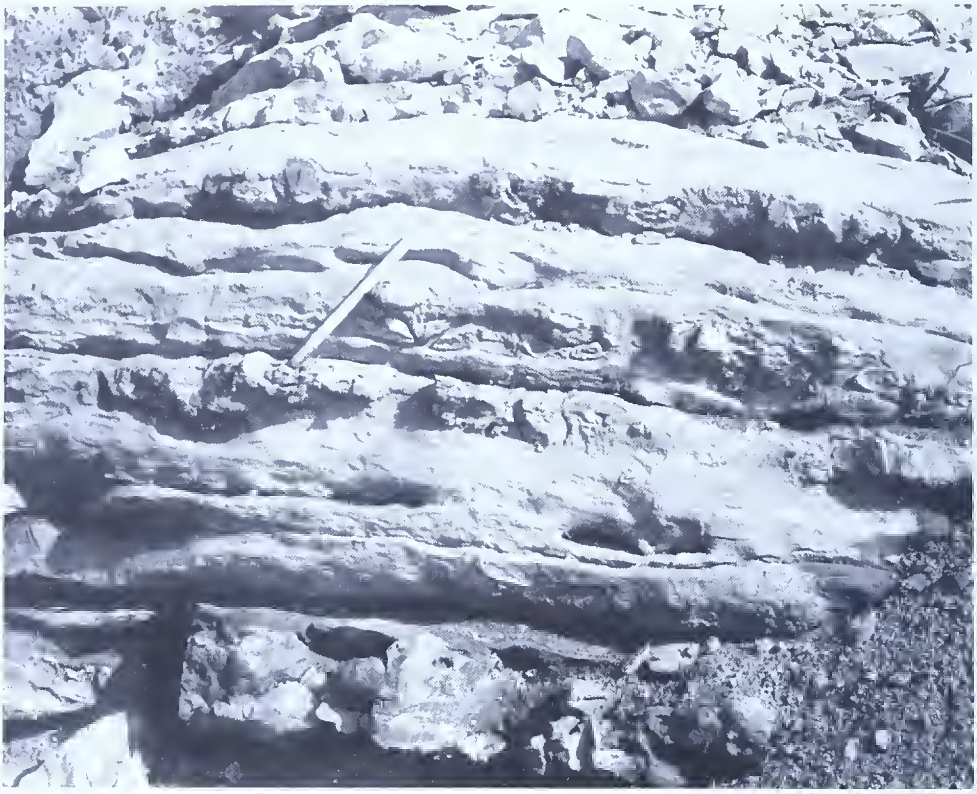


Figure 22. Thin bedded slightly nodular, very finely detrital St. Paul limestones with protruding black chert nodules. From middle of group just south of Chambersburg along U.S. Route 11. Abundant silicified fossils occur at this horizon.

The following bryozoa were collected about 9500 feet south of the town square in Chambersburg on the south side of the Western Maryland Railroad. They were identified by W. J. Sando and O. L. Karklins of the U.S. Geological Survey:

Lamottoporoid bryozoan
Diplotrypoid bryozoan
Lichenaria? sp.

This represents an early Middle Ordovician age. The St. Paul Group as a whole is of lower Middle Ordovician age assigned to the Marmor and Ashby Stages by Cooper (1956).

Chambersburg Formation

The Chambersburg Limestone was named by Stose (1906, p. 211) to designate the Middle Ordovician cobbly limestones typically exposed near Chambersburg. Subsequent work, mainly of a biostratigraphic nature, has included the studies of Cooper and Cooper (1946) and Craig (1949). It outcrops in a narrow belt along the eastern limit of the Martinsburg terrane. Exposure is extremely poor in the area, especially north of Chambersburg.

Because of its narrow width, the Chambersburg does not have a typical topographic expression, but underlies a flat, low area. The limestone cobbles derived from the formation litter the ground and as such are distinctive. In addition, the outcropping bedrock does not protrude above the soil as ledges or knobs, but normally is at the same surface level as the adjacent regolith; it seems to 'peek' through the regolith. None of the other carbonate units outcrop in this subdued manner.

There is only one good complete exposure of the Chambersburg in eastern Franklin County. This is the section in the spur of the Pennsylvania Railroad cut located 8,000 feet N60°W of Kauffman where the main line of the Pennsylvania Railroad passes through that town. This section has been measured by several workers and a detailed description is presented by Cooper and Cooper (1946, p. 59).

From their description it is apparent that the general lithologic aspect of the Chambersburg is that of a sequence of cobbly limestone. This impression is even more striking in natural exposures protruding through the regolith as most of the more massive appearing units in the railroad cuts tend to

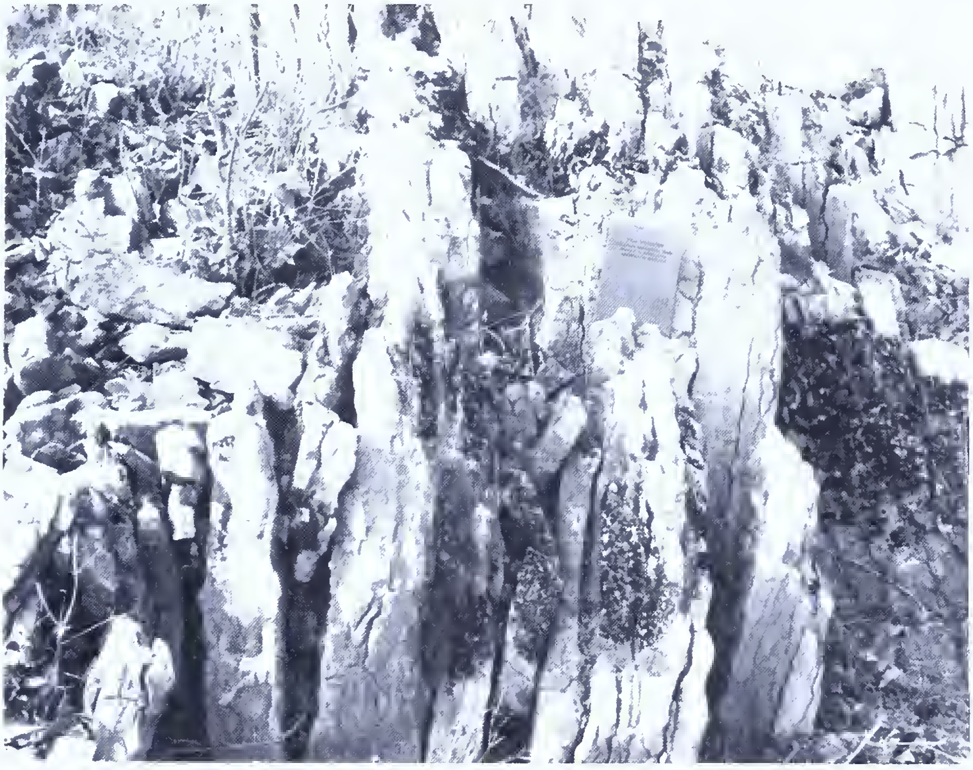


Figure 23. Vertical strata showing typical thin bedded slightly cobbly limestones of the Chambersburg Formation.

become cobbly upon prolonged weathering. The cobbly habit of the limestone is the result of wavy laminations or shaly partings that cross the bending at high angles. Upon weathering they form rounded lenticular pieces resembling rough cobblestones or squarish nodules. The writer has not been able to subdivide the Chambersburg into mappable units because of similarity of lithology throughout the sequence and generally poor outcrop.

A partial section of the lowermost 380 feet of the Chambersburg Formation was measured south of Chambersburg (Locality 4, Appendix). There are basically two major lithotypes here—a thin-bedded and a thick-bedded, cobbly weathering limestone (Figures 23 and 24). The contact with the underlying St. Paul Group is abrupt but conformable. The contact with the Martinsburg shales is exposed about 1000 feet to the south in the bank of Cononococheague Creek. Here, over a stratigraphic interval of about 30 feet are interbedded Chambersburg type limestones, platy argillaceous black limestones, and dark gray shales typical of the Martinsburg Formation. This upper contact is partially exposed at several localities in the mapped area and it is always transitional. These transitional beds were termed the Oranda by Craig (1949), but the application of this name to these beds is in question as they differ markedly in lithology and age from the type Oranda beds in Virginia.

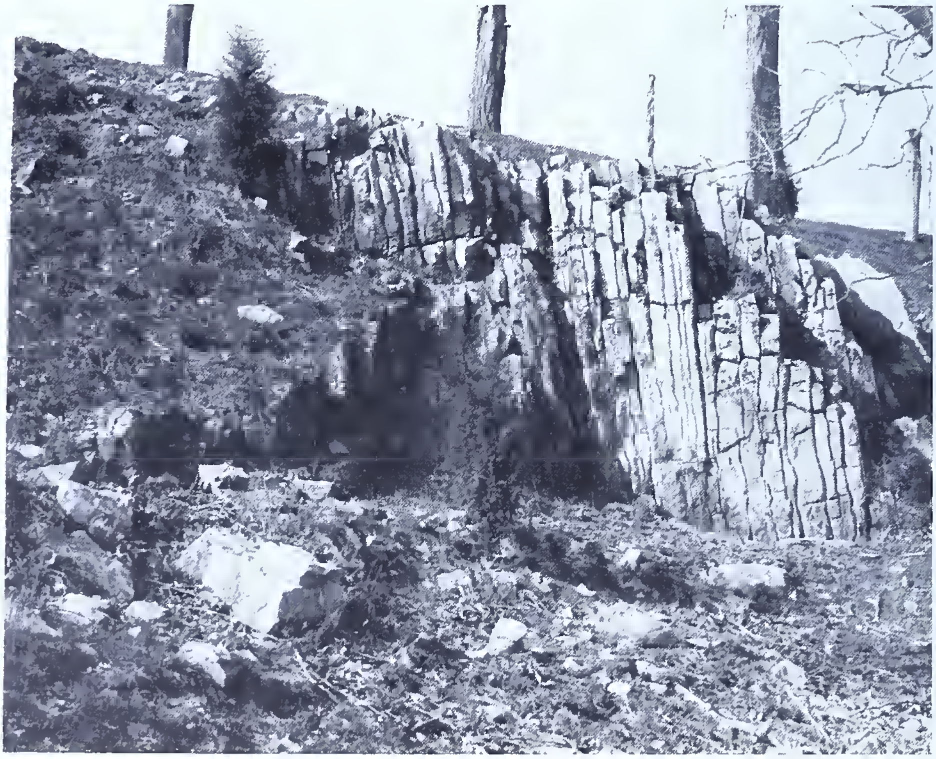


Figure 24. Vertical strata showing typical thick bedded slightly cobbly limestones of the Chambersburg Formation.

Craig (1949) noted some thin metabentonite interbeds in this region but I have not observed them. Certainly they are not as prominent or thick as those to the west in Path Valley area.

At Rocky Spring, in the northernmost part of the mapped area, the Chambersburg occurs as an isolated block bounded by faults. It appears that the beds here are in the upper part of the formation. They contain a 5-foot thick interbed or lens of Martinsburg type shale and hard, very fine-grained greywacke to greywacke siltstone that is poorly graded. This lithology has not been observed elsewhere in the Chambersburg Formation.

The thickness of this formation is about 750 feet in southeastern Franklin County (Root, 1968). To the north, near Middle Spring the formation is about 430 feet thick (Craig, 1949). Although no complete sections are present in the mapped area thickness, structurally determined by width of outcrop belt, appears to be about 600 feet thick near Chambersburg. The thickness determined here is consistent with southeastward thickening of the formation.

The age of the Chambersburg has been firmly determined as Middle Ordovician, and it is correlated with the Black River and lower Trenton Groups in New York State.

Martinsburg Formation

Martinsburg Formation was the term applied by Keith (1894) to the shale hills near Martinsburg, West Virginia. As these shales can be traced north into Pennsylvania, Stose (1909, p. 10) applied the term in Franklin County and later workers extended the term as far north as the Delaware River. The Martinsburg is the least understood geologic unit in Franklin County. Such basic facts as thickness and stratigraphic sequence are still unknown because of the paucity of outcrop and structural complexity.

The Martinsburg is restricted to the western portion of the mapped area. It forms a broad belt widening from southwest to northeast (Plate 1). It is also present in a small area south of Chambersburg where it occurs on the limb of a plunging fold.

Characteristically the Martinsburg forms a low plateau declining from elevations of about 750 feet in the north to 700 feet in the south. This surface has been termed the Harrisburg peneplane by Stose (1909, p. 10). The shale plateau, which is about 50 to 100 feet higher than the adjacent limestone terrain, is highly dissected by small streams which flow in steep, rugged, and narrow valleys. Conococheague Creek is the only stream that has cut down sufficiently to form a narrow flood plane. The difference in morphologic expression between the limestone and shale terranes as shown on the topographic base (Plate 1) is striking.

Because of the limited exposure and structural complexity, it is difficult to determine a Martinsburg lithologic sequence in the area. Stose (1909, p. 10) states that the lower part of the formation is black, carbonaceous and fissile

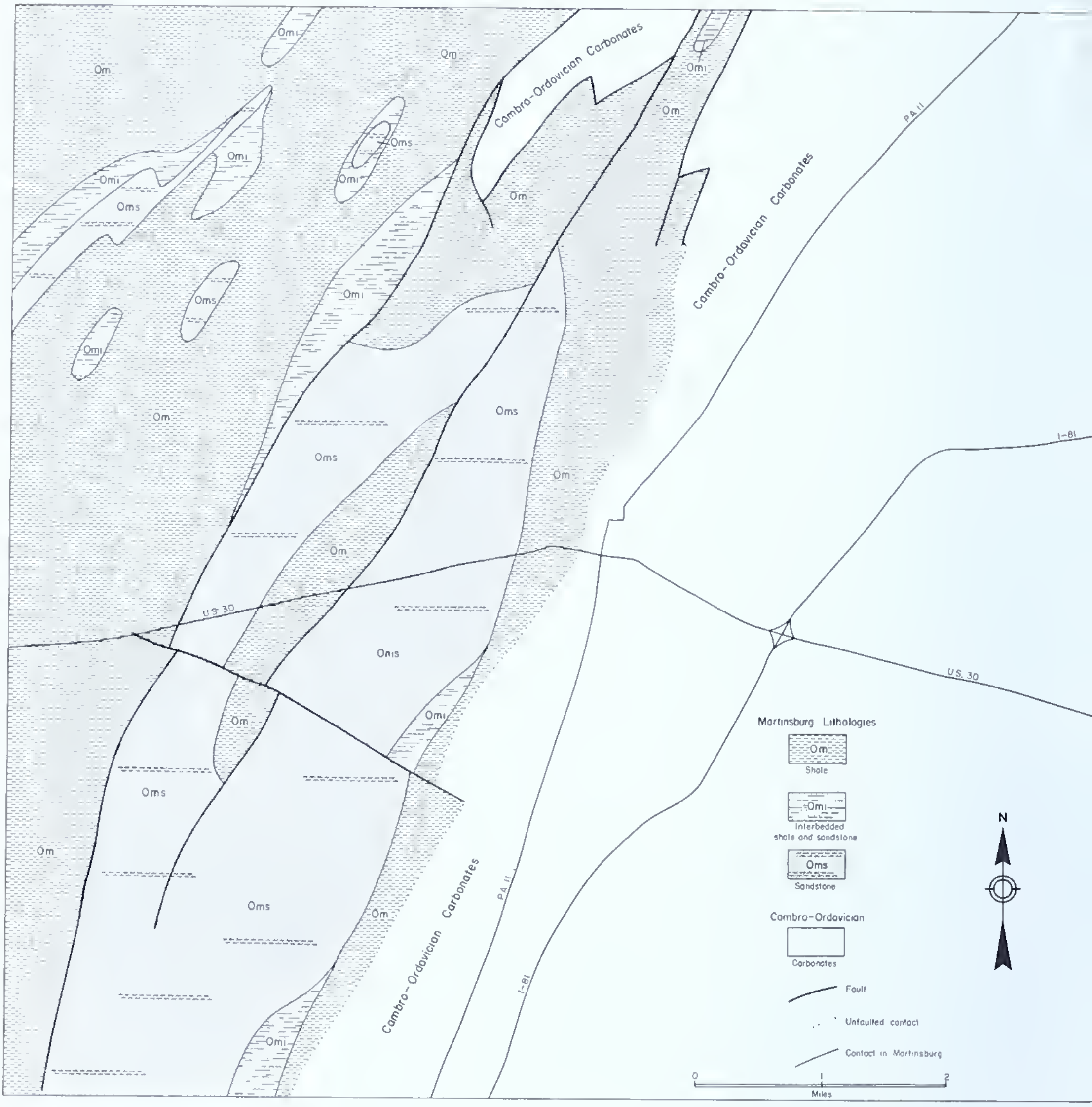


Figure 25. Distribution of the various outcropping lithologies in the Martinsburg Formation in the Chambersburg 7½-minute quadrangle.

becoming calcareous near the base and grading into the Chambersburg Formation. In the middle of the formation the shale is dark and slightly calcareous. The upper portion of the formation is composed of a soft sandstone of yellow-green color, but west of Chambersburg it is exceptionally hard, coarse grained, and thick bedded. Based on a regional study McBride (1962, p. 42) concluded that the Martinsburg is composed of a lower shale member which passes upward into a member of interbedded graywacke and shale (Flysch). In the area of McConnellsburg Cove (Pierce, 1966) divided the Martinsburg equivalent (Reedsville Formation) into a basal black shale, a middle shale with minor beds of siltstone and sandstone, and an upper shale cut by channels of coarse-grained fossiliferous sandstone.

In this area three major lithologies—shales, sandstones, and interbedded shale and sandstone—are recognized in the Martinsburg. As is common throughout the region shale is most abundant, but sandstones also are present in moderate amounts. The distribution of these rock types is shown on Figure 25, adapted from Plate 1. It appears from this distribution that the lower part of the Martinsburg are shales (Figure 26) which are then overlain by sandstones (Figure 27). The interbedded shale and sandstone (Figure 28) appears to occur between these two lithologies. Undoubtedly more shale occurs above the sandstone as beds of the uppermost Martinsburg do not occur in this portion of the Massanutten synclinorium. The sandstones are considerably thicker and coarser than the sparse sandstones in the uppermost part of the Martinsburg close to the Bald Eagle-Juniata Formations on the west side of the valley.

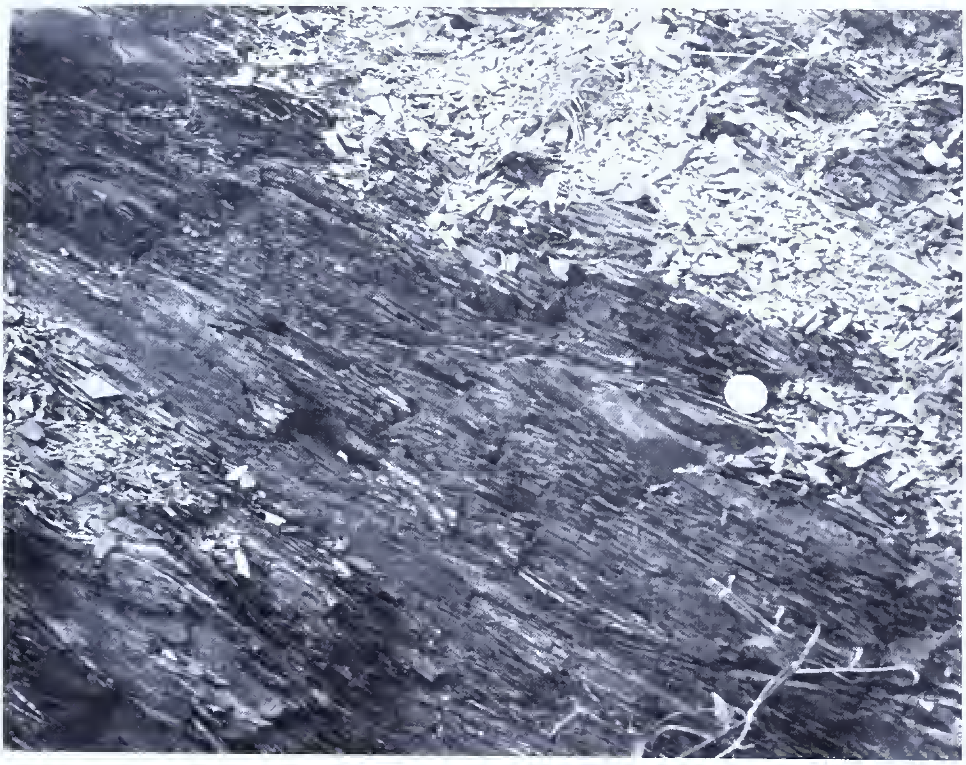


Figure 26. Fresh road cut of shaly lithofacies of the Martinsburg Formation. Determination of primary bedding is difficult here. Upon weathering this outcrop will become rubbly.

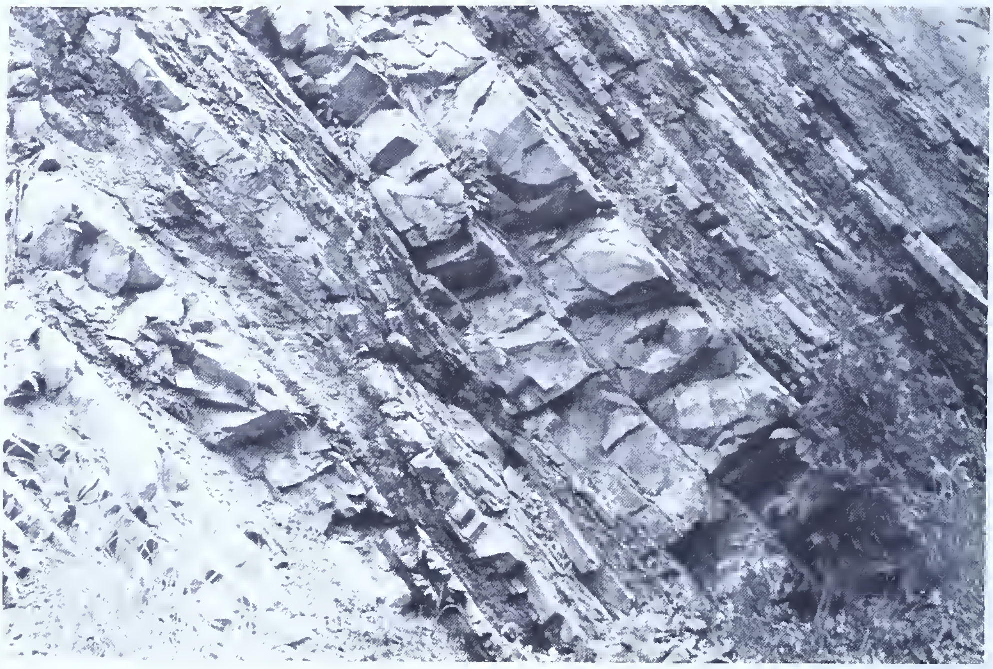


Figure 27. Four-foot thick graywacke bed in sandy portion of the Martinsburg Formation. Beds are overturned as shown by sole markings and graded bedding. Exposed near Social Island.

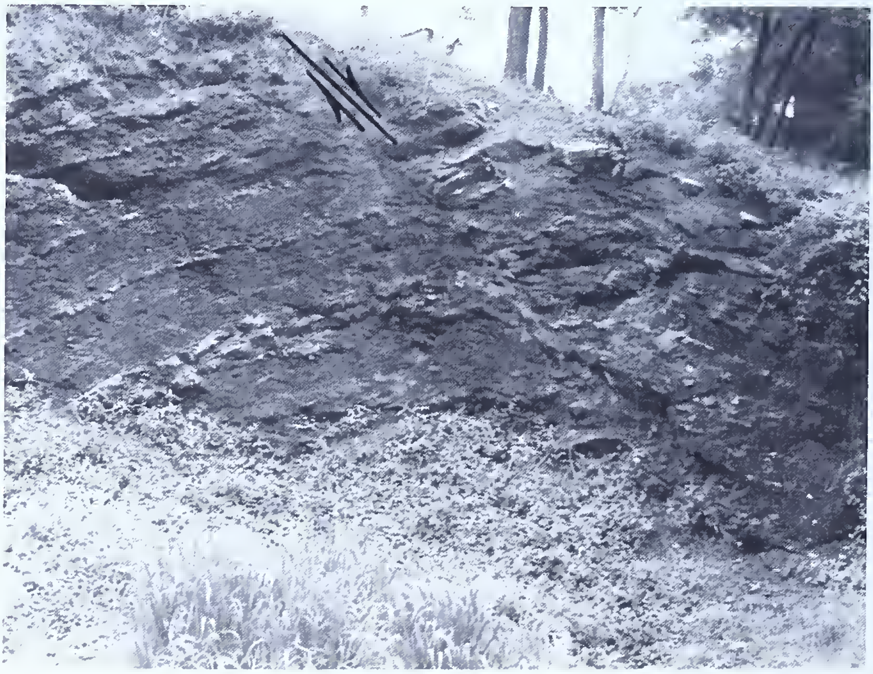


Figure 28. Antiform in interbedded shale and fine sand lithofacies of the Martinsburg Formation at Social Island. Normal fault with 5 feet of displacement, dips east.

The lower shaly part of the Martinsburg is not exposed to advantage except along the cuts of the Pennsylvania Railroad between Williamson and Stone Bridge in southern Franklin County. However, the structural complexities have not been resolved in this series of exposures. Usually the shales weather yellowish-brown (10YR 6/4) and because they break into small pieces, frequently in the shape of pencils, as a result of a pervasive fracture cleavage (Figure 26), they usually exhibit the same coloration on an interior surface. However, the original dark to medium gray color can be seen in some fresh cuts.

Exposures in the upper sandy portion of the Martinsburg are better than in the shales. There are some good exposures close to the contact with the carbonates especially on the west side of Conococheague Creek at Social Island. Sandstones predominate over the shales. The sandstones are fine to very fine-grained, dark gray to dark buff graywackes in beds up to 6 feet in thickness although they average considerably less (Figure 27). The sandstones are poorly graded throughout much of the section; the grading is frequently shown by subtle features such as color contrast and surface texture rather than obvious grain size variation. Bases of the beds are frequently irregular, indicating groove casts. In some instances granules and fine pebbles have accumulated in the lowest part of a groove cast and are an excellent indicator of superposition of strata. Most of the sandstones lack internal structure such as lamination and cross stratification.

The interbedded shale and sandstone show characters of both previously described lithologies. Generally the sandstones are finer-grained, frequently they are siltstones, and thinner bedded than in the wholly sandstone lithology (Figure 28).

The thickness of the Martinsburg has not been resolved in the Cumberland Valley. Stose (1909, p. 10) calculates the thickness of the Martinsburg at 2,000 feet with the shales constituting 800 feet and the sandstones 1,200 feet but this figure is subject to question. Along the Great Valley from Virginia to New Jersey thickness estimates range from 2,250 to 11,000 feet (McBride, 1962, p. 43). At Letterkenny Depot a partial section of intermittently exposed Martinsburg shales was computed to be at least 5,000 feet thick. However, there could be faulting in the covered portion of the section duplicating some of the section. In Path Valley and the McConnellsburg area (Pierce, 1966) maximum thickness is estimated to be 2,500 feet and minimum thickness estimated to be 1,000 feet. However, Pierce (1966, p. 19) concludes that thickness estimations are possibly subject to large error as a result of poor exposure and complex deformation of this very ductile unit. Much work remains to be done here before the Martinsburg Formation can be discussed in terms of lithologic succession, stratigraphic framework, and geologic history.

DEPOSITIONAL HISTORY

The depositional history of the Cambrian and Ordovician sediments from the Elbrook Formation to the Martinsburg are set forth briefly in this section. The restricted area of this report and limited exposures permit only the general interpretation that miogeosynclinal sedimentation occurred principally in a stable, shallow, open-marine sea until the Middle Ordovician when conditions were less stable and seas became deeper.

The carbonate beds of the Zullinger-St. Paul sequence were deposited in an environment probably somewhat similar to that of the present Bahama Banks platform. The seas were so shallow that slight movements of sea level could shift environments from shallow open marine (detrital, oolitic, and intraformational conglomeratic sediments) to intertidal (stromatolitic and micritic sediments) or supratidal (algal mat dolomites and birdseye micritic limestones).

Environmental conditions changed during the deposition of the Chambersburg Formation. The argillaceous composition and cobbly character of the limestones indicate conditions of deeper marine water than existed during the deposition of the older sediments and development of a paleoslope (Wobber, 1967). Bentonite beds and probable slight unconformities within the formation are an indication of the beginning tectonic instability of the region. As the basin deepened and regional tectonism became more pronounced, the flysch sediments of the Martinsburg Formation were deposited.

SURFICIAL DEPOSITS

The surficial deposits for purposes of this report are shown simply on the geology map (Plate 1) as alluvium. This classification does not do justice to the variety of surficial deposits that can be distinguished. On the west side of the valley, Pierce (1966) distinguished screes, block fields, and shale-chip rubble on interfluves; rubble ridges, debris slides and avalanches, rubble fans and rubble valley fills, modern alluvium and roundstone diamicton on valley bottoms.

The term alluvium is used here to include all detrital accumulations deposited by modern rivers. Thus it includes all the recent stream flood plains in the area. Older terrace deposits occur as isolated remnants along some valleys or, less commonly, on interfluves, but are not shown on the geologic map. These ancient alluvial deposits can be recognized by abundant well rounded quartzite cobbles and boulders that are strewn on the ground. Transported regoliths on the interfluves and limestone residuum and soil were not studied in this report. An extensive report by Higbee and others (1938) concerns the soils of Franklin County and includes a large scale map.

STRUCTURAL GEOLOGY

INTRODUCTION

The structural geology of this general region has been described in considerable detail on the south by Root (1968), on the east by Fauth (1968), and on the west by Clark (1970). In a more regional sense it has been discussed by Cloos (1947) and MacLachlan and Root (1966). As this is involved in the same system of processes and deformation mechanics that were described in the quadrangles to the south (Root, 1968) this aspect will only be referred to briefly. However structural elements will be described in detail.

GENERAL STRUCTURAL GEOLOGY

South Mountain at the north end of the Blue Ridge physiographic province is composed of a core of Precambrian Catoctin metabasalts and metarhyolites, rimmed by quartzite ridges of the Weverton, Harpers, and Antietam Formations (Figure 29). The Great Valley is floored by the Cambrian and Ordovician carbonates and by shales of the Martinsburg Formation. For purposes of structural consideration the writer follows the usage of Cloos (1951, p. 124) and divides the area into two major structural elements, the South Mountain anticlinorium on the east and Massanutten synclinorium on the west (Figure 30). Essentially the Cumberland Valley carbonates are part of the autochthonous South Mountain anticlinorium. Rocks from the Catoctin greenstones through the Middle Ordovician carbonates are involved in related folding and faulting. The flow cleavage (S_1) and fold pattern geometry are reflected through the entire sequence of rocks indicating that they have a common deformational history.

Most major faults are rectilinear high-angle reverse faults. Some individual folds and faults can be traced more than 30 miles, and further extension is limited only by lack of detailed mapping. Although the structural geology is complex it is extremely regular and maintains this regularity probably to Elkton, Virginia, south of which the Blue Ridge may be involved in considerable thrusting. The following description of geometry and mode of deformation of the South Mountain anticlinorium is from the excellent work of Cloos (1947, p. 845) based on analysis of oolite deformation in the Cumberland Valley of Pennsylvania and Maryland:

> The South Mountain fold is a large asymmetrical overturned anticline. Its axial plane dips to the southeast, and its crest is the western slope of South Mountain. Cleavage dips steeper in the upper than the lower limb thus forming a fan which opens to the northwest. All parts of this fold participate and reveal an identical deformation plan: fold axes are nearly horizontal, cleavage dips southeast, lineation is in the cleavage plane normal to the fold axes, also dipping east. All formations including the volcanics participate. Intensity of deformation varies greatly within the fold depending on (1) physical properties of materials (2) location within the fold and (3) geographical location. Approaching South Mountain from the west intensity grows gradually, is strongest in the lower limb,

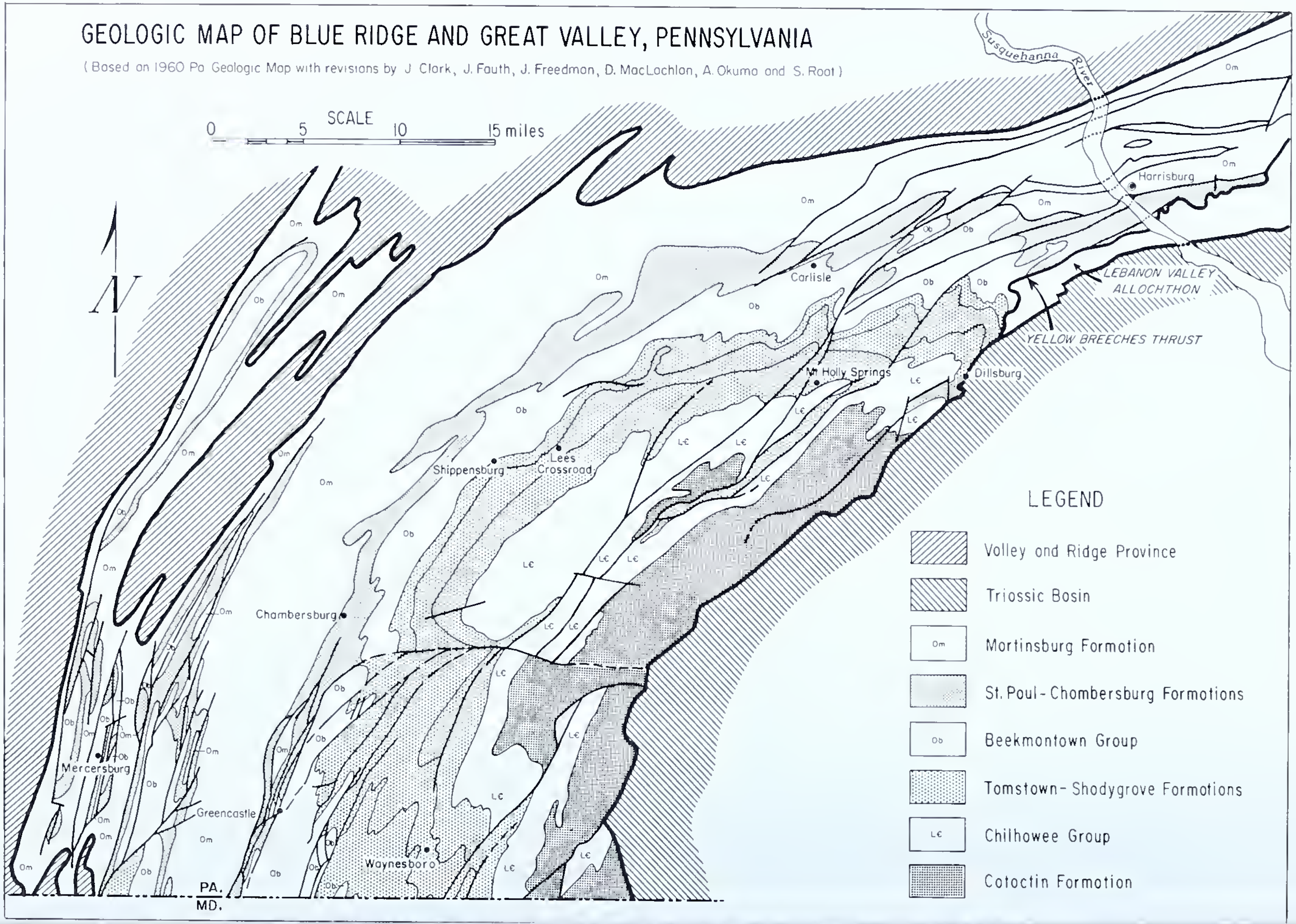

GEOLOGIC MAP OF BLUE RIDGE AND GREAT VALLEY, PENNSYLVANIA
(Based on 1960 Pa Geologic Map with revisions by J Clark, J. Fauth, J. Freedman, D. MacLachlan, A. Okuma and S. Root)
SCALE
0
5
10
15 miles
N
Susquehanna River
Harrisburg
Carlisle
Mt Holly Springs
Dillsburg
LEBANON VALLEY ALLOCHTHON
YELLOW BREECHES THRUST
Shippensburg
Lees Crossroad
Chambersburg
Mercersburg
Greencastle
Waynesboro
PA.
MD.
Om
Ob
L€
LEGEND
Valley and Ridge Province
Triassic Basin
Om Martinsburg Formation
St. Paul-Chambersburg Formations
Ob Beekmantown Group
Tomstown-Shadygrove Formations
L€ Chilhowee Group
Catoctin Formation

Figure 29. Geologic map of northern Great Valley and Blue Ridge ar

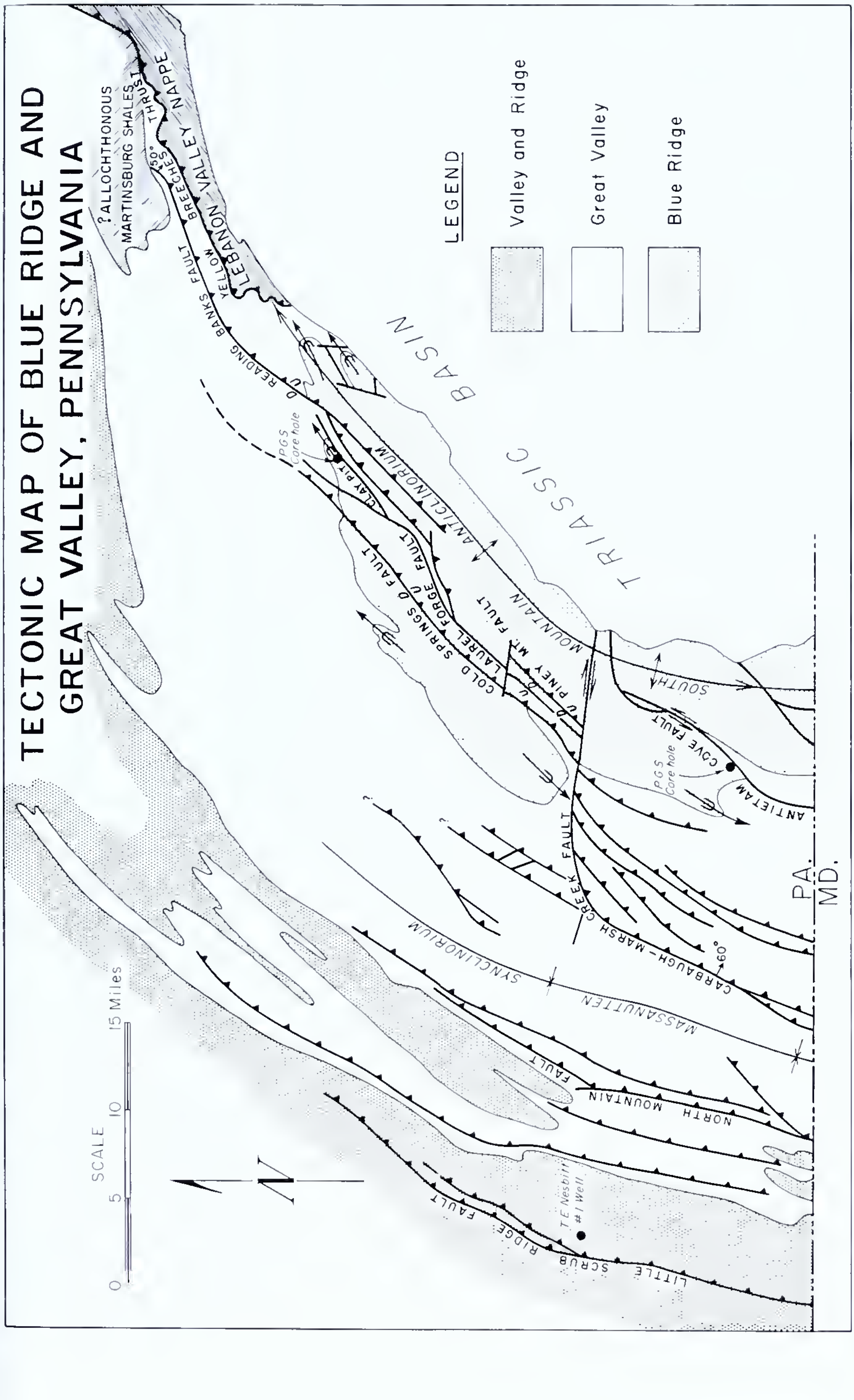


Figure 30. Tectonic map of northern Great Valley and Blue Ridge area.

decreases toward the crest and upper limb. Abrupt changes as would be expected large-scale thrusting were not observed, the deformation seems to have been absorbed within a much wider complex.

Faults

There are several major faults (Figure 31, and Plate 1) that extend across the mapped quadrangles and define the structural pattern for a considerable extent.

Carbaugh-Marsh Creek Fault

This fault has been described to the south by Root (1968), MacLachlan and Root (1966) and to the east by Fauth (1968). It was shown by these workers that this fault begins as an east-west subvertical right lateral tear in the Catoctin volcanics near Cashtown. Judging by offset of the Catoctin volcanics, there is about 2½ miles of right lateral slip along the fault (Fauth, 1968). Near Chambersburg the fault swings southerly (Plate 1, Figure 31) and assumes a northeast-southwest trend near Greencastle. As the fault parallels the regional tectonic grain it clearly becomes a thrust fault. In a quarry at Greencastle limestones of the St. Paul Group are thrust over shales of the Martinsburg on this fault that dips at 60° to the east. The fault probably extends to Martinsburg, West Virginia, so that it is the most extensive fault in the region. In the southern part of the Cumberland Valley it serves neatly as the boundary between the South Mountain anticlinorium on the east and the Massanutten synclinorium on the west.

East of the map area the Antietam Cove fault (Figure 30) is related to the Carbaugh-Marsh Creek fault as it appearently joins with it near Cashtown. These two faults serve to delimit a block that has been thrust to the east. In this block are several minor thrusts that are derived from eastward translation of this block (Figures 30 and 31). Because they pass into the tear fault segment of the Carbaugh-Marsh Creek fault they are considered merely to be splays from this major fault. These faults have each a maximum of about 2,500 feet of stratigraphic displacement. Maximum stratigraphic displacement on the Carbaugh-Marsh Creek fault, near the Potomac River, may be as much as 5,000 feet (Sando, 1957, Plate 1).

Scotland Fault

This fault appears on the south at the tear fault segment of the Carbaugh-Marsh Creek fault (Plate 1, Figure 31). It trends parallel to the tectonic grain north of the Carbaugh-Marsh Creek fault. The fault is of limited extent as it does not appear to extend north of Scotland, however, as the fault would be entirely within the Zullinger Formation north of here, it would be difficult to detect. The highly contorted beds in the road cut at the railroad overpass in Scotland indicate that the fault extends this far north. Displacement across the fault seems modest—no more than several hundred feet stratigraphically.

The precise nature of the fault is not clear. At the nose of the fold near the Carbaugh-Marsh Creek fault the relationship is such that the easterly block seems to be downdropped relative to the westerly blocks. It appears that the easterly block has been rotated about a horizontal axis so that dips steepen and the width of outcrop decreases on the east side of the fault. Possibly the entire easterly block is uplifted and the anomalous relations at the nose are due to steeper dips on the eastern block. If the Scotland fault merges with the Carbaugh-Marsh Creek fault, rather than emerges from under the plate, it may contain a component of second order left lateral slip related to the primary first order right lateral Carbaugh-Marsh Creek wrench (Moody and Hill, 1956). However, at present the former idea seems most credible.

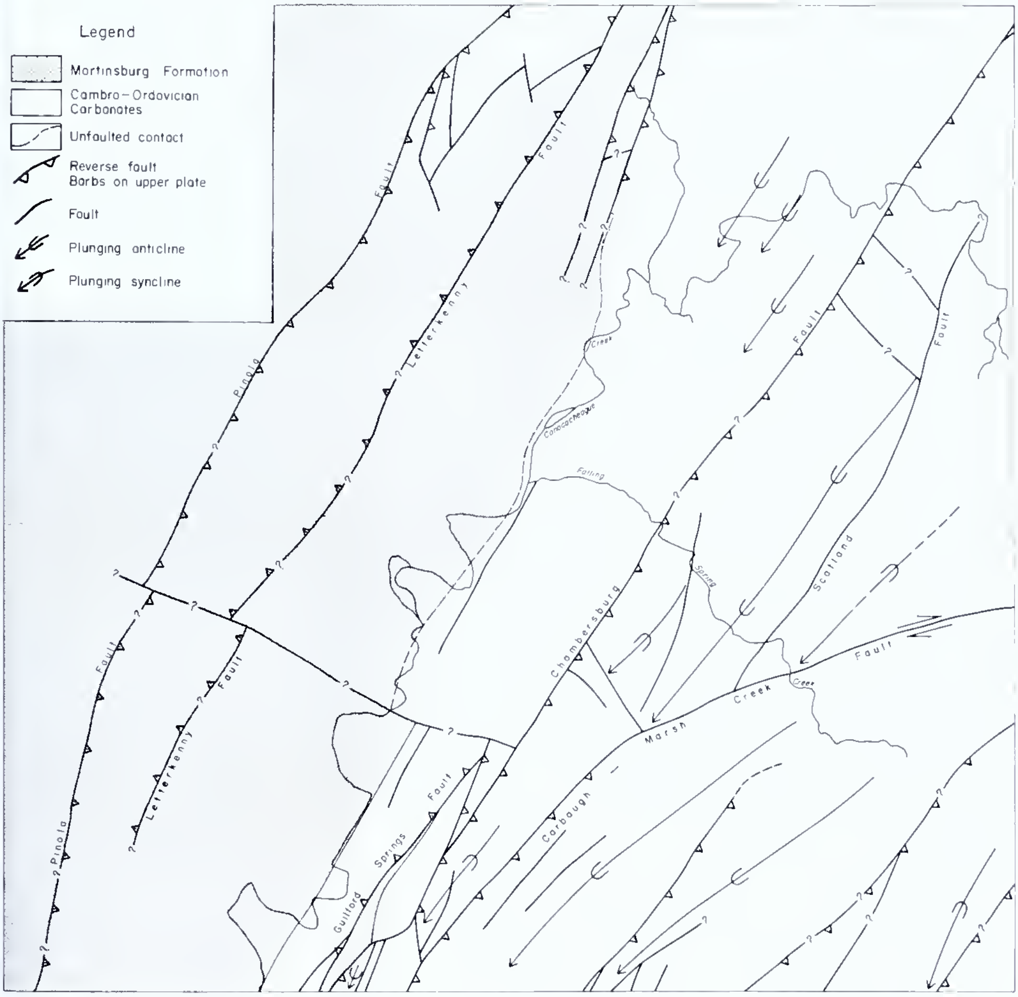


Figure 31. Major structures of the report area.

Chambersburg Fault

This fault appears on the south near Guilford Springs (Plate 1, Figure 31) and trends northeast beyond the limit of geologic mapping. It probably extends beyond Shippensburg. The extent of the fault and considerable amount of stratigraphic displacement across the fault (middle Rockdale Run against St. Paul, about 1000—1500 feet) indicates that it is of considerable local, and probably regional importance.

Because older beds occur on the east side of the fault it is considered to be a high angle east-dipping thrust, similar to other demonstrable east dipping high angle thrusts in the region. Near Marion the fault swings to the south and appears to be truncated by the Carbaugh-Marsh Creek fault.

It appears that this fault and the associated anticline, near Stoufferstown on the east (Plate 1, Figure 31) pass under the Carbaugh-Marsh Creek thrust plate. This is of importance in establishing a chronology of deformation.

Pinola Fault

It is difficult to determine precisely where this fault is initiated on the south (Plate 1, Figure 31) as it is virtually impossible to trace faults within the Martinsburg terrain. The fault trace is projected through the Martinsburg on the basis of a ridge forming unit that extends south from Rocky Spring. The fault is readily mappable northeastward beyond the area of this report from Rocky Spring past Pinola to Middle Spring. Along much of this segment of the fault St. Paul carbonates are thrust upon shales of the Martinsburg so that the fault is readily mapped by reconnaissance. The fault may continue north of Middle Spring but as it would here be in a terrain wholly of limestone detailed mapping is necessary to define the fault. The extent of the fault and moderate amount of displacement indicates that it is of local importance.

The fault is shown as a single continuous feature on the geologic map (Plate 1). However near Rocky Spring it changes trend abruptly from north-south to northeast-southwest, a divergence of 30-35°. It is conceivable that this divergence is actually caused by the interaction of two separate thrusts rather than the deflection of a single thrust surface. However, based on experience with similar structures in this region I consider it to be a single deflected fault surface. The position of the fault in the Martinsburg terrane is inferential. As older beds occur on the east side of the fault I consider it to be an east dipping high angle thrust fault similar to other faults of this nature in the Cumberland Valley. As this fault truncates the Letterkenny fault and some folds it is considered to be late-formed. An alternative would be that this is a west-dipping normal fault but this is highly unlikely for a late-formed fault in a region of such compression.

Guilford Springs Fault

This fault extends from just south of Greencastle in southern Franklin County to Guilford Springs (Plate 1, Figure 31). The southern segment of the fault and associated mechanics were described in detail by Root (1968, p. 66-72). It was concluded that this was a west dipping thrust upon which material moved eastward, out of the Massanutten synclinorium on the west, as a consequence of flexural slip folding, thus giving the relation of younger beds on the east side of the fault. This fault was shown to be formed early, as it is overridden at its south end by the Carbaugh-Marsh Creek thrust plate. Also it is believed that the fault may now be vertical or even dipping subvertically to the east as a result of external rotation of the fault by later tight folding and overturning of fold limbs. It terminates, in this area, against an east-west cross fault about 3,500 feet north of Guilford Springs.

Letterkenny Fault

This fault, along the north edge of the mapped area (Plate 1, Figure 31) is of small extent and displacement. However, it is important in analysis of the structural mechanics of the region. This is one of the few faults in the region that parallel tectonic grain, but in which younger beds occur on the east side of the fault. It is therefore considered to be of the same origin as the Guilford Springs fault—an early formed west dipping thrust that originated during flexural slip folding of the area and upon which material moved out of the syncline on the west onto the anticline on the east. As dips in the carbonate block west of the fault are moderate, the fault is probably still west dipping; but it has been steepened from its initial inclination by later external rotation.

The fault is postulated to continue southwest through the Martinsburg terrane on the basis of a broad ridge that appears to be associated with the fault and continues beyond the carbonate-shale contact. An east-west cross fault between the Pinola fault and the Letterkenny fault limits the carbonate block on the south. Both the position of this fault and the straight surface trace are open to question. However, there is a fault on the south limiting the carbonate block between these two faults and carbonates do not form the plunging nose of a simple second order anticline upon the South Mountain anticlinorium as shown by Stose (1909). Because the Pinola fault truncates the Letterkenny fault the latter fault is clearly the older.

Other Faults

There are many other faults in the mapped area (Plate 1, Figure 31) but they are all of small extent and displacement, and only locally significant. Only some of the more important ones are described here.

There is a concentration of small faults between the Guilford Springs fault and the Carbaugh-Marsh fault. They probably are a consequence of the movement of the Carbaugh-Marsh Creek thrust plate over the footwall carbonates.

Terminating the Guilford Springs fault on the north is a small cross fault trending westnorthwest-eastnortheast. This is not the usual type of fault across which structural features are offset. However, no structural features can be matched across the fault. As the same formations occur on either side of the fault but with entirely different structures, it is a discontinuity on either side of which semi-independent folding occurred. It may be temporally and spatially related to the Carbaugh-Marsh tear fault segment as it is close to it and has the same orientation. However, the senses of apparent slip are opposed so that a relationship would be complex.

Folds

The region is dominated by two folds—the South Mountain anticlinorium on the east and the Massanutten synclinorium on the west (Figure 30). The mapped area lies athwart the common limb as well as the axial portion of the synclinorium. Structure in the Martinsburg terrane is such that it is virtually impossible to locate the axial part of the synclinorium. The synclinal structure shows up by the development, on the west, of the carbonate cored Mercersburg anticlinorium (Figure 29).

Large folds cannot be mapped in the Martinsburg because there are no persistent marker beds or other indicators of internal stratigraphy. There is much small scale folding (Figure 28) that obscures major structures, and outcrop, away from roadcuts, is scarce.

Folds can be mapped in the carbonates with a considerable amount of precision south of the Carbaugh-Marsh Creek fault. North of the fault folds are mapped with less certainty; the series of complex folds west of the Chambersburg fault, as shown by the sinuous trace of the St. Paul-Beekmantown contact is partly interpretive. There are probably several faults in this terrain that modify the basic fold pattern but are not recognized because of sparse outcrop.

South of the Carbaugh-Marsh Creek five second order anticlines are developed in the carbonates (Figures 29 and 30). These were projected as far south as the Potomac River (Root, 1965) a distance of 30 miles.

Mapping is not as extensive north of the Carbaugh-Marsh Creek fault so that the extent of comparable folds is not determined. However, they are not as abundant or extensive as folds south of the fault. There is a partial anticline developed between the Scotland and Chambersburg faults which disappears near Scotland. As mentioned previously there are some small folds developed in the carbonates west of the Chambersburg fault. Although the fold pattern is partly interpretive the major anticline on which the small folds are developed, probably has an extent of about 10 miles or so.

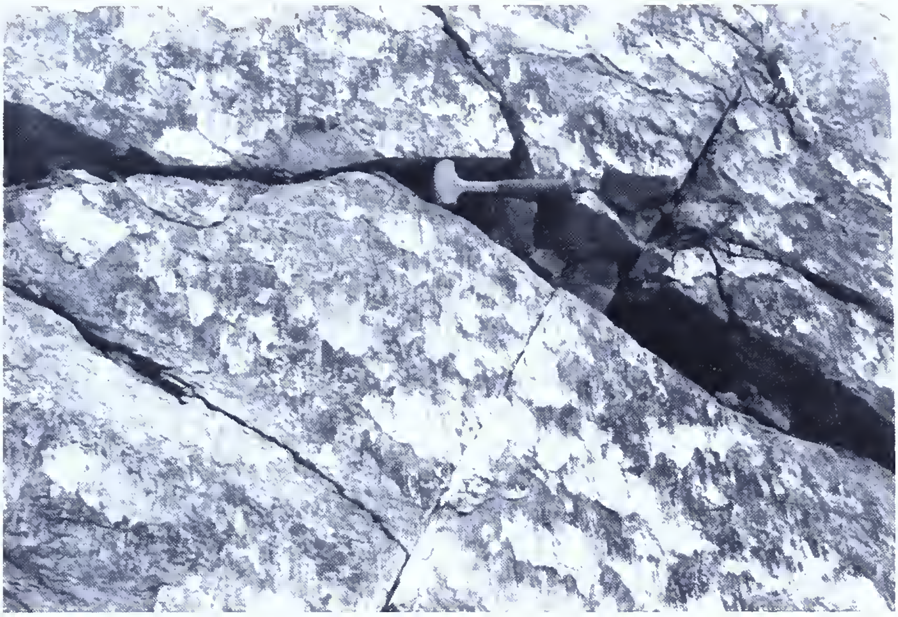


Figure 32. Stonehenge Formation in quarry at New Franklin. Note development of accretionary calcite on slickensided surface of bed. Based on consideration of fold mechanics the "steps" on the calcite oppose the direction of movement. Each bedding surface in the Stonehenge here is similar to this indicating flexural slip mechanics.

The mechanics of folding in this region have been discussed by Root (1968), as follows:

> Most of the folds in units younger than the Elbrook Formation formed by interstratal slip during flexure folding; certainly the brittle shattering of faulted St. Paul and Beekmantown limestone at the Kauffman farm section, 6,000 feet west of Marion (MacLachlan and Root, 1966, Figure 10) do not indicate the conditions necessary for shear folding. The quarries of Valley Quarries, Inc. at New Franklin expose a thick sequence of vertical Stonehenge limestone in which almost every bedding surface is slickensided, showing general interstratal slip congruent with fold kinematics. However, a few of the slickensides indicate motion in a horizontal or subhorizontal sense, parallel to the fold axis, demonstrating that more than simple folding of the sediments is involved. Subhorizontal transport may reflect movement during translation of the block bounded by the Carbaugh-Marsh Creek fault. Many of the bedding slip planes have extensive calcite slickensided surfaces with well developed steplike breaks. On the footwall the abrupt step usually faces down. Flexure-slip mechanics would indicate that the abrupt step faces a direction opposite that in which the other block moved. This relationship has been observed elsewhere by Tjia (1964) and reproduced experimentally by Riecker (1965) who ascribes this to violent elastic rebound of stressed projectives on the sheared face during slip.

This feature has been described in detail by Norris and Barron (1968) who caution against indiscriminate use of these steps to determine relative fault motion. Figure 32 shows the slickensided bedding surface at the New Franklin quarry.

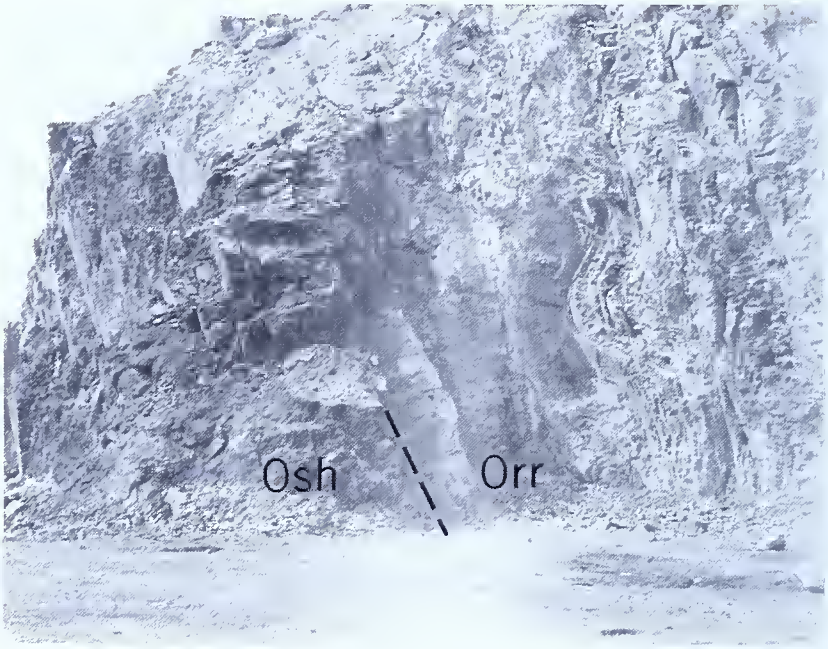


Figure 33. Thin limestone with clay and cherty interbeds at right of photo are the base of the Rockdale Run Formation (Orr). They are incompetent and buckle as a conforming structural lithic unit whereas the more massive, competent limestones of the underlying Stonehenge Formation (Osh) at the left of the photo buckle as dominant members of a structural lithic unit. Major synclinal axis is several hundred meters to the right of photo. Quarry at New Franklin.

Where the Martinsburg contains graywacke beds (Figure 27) that are folded, such as at Social Island, these bedding surfaces are extensively slickensided. The slickensides are generally normal to the fold axes—the same kinematics apparent in the Stonehenge beds at the New Franklin quarries. This kinematic geometry is characteristic of the region as a whole.

Only in a very few places is folding by other than flexural slip mechanics. One such place is the road cut at the railroad overpass in Scotland. Here beds of the Zullinger Formation are tightly folded in response to movement along the Scotland fault. The folded sequence consists of the interbedded limestone and dolomite. The more ductile limestones have flowed around the noses of folds so that the general deformation also includes elements of flexural flow.

The quarries at New Franklin also show this to excellent advantage. Massive limestones of the Stonehenge are involved in flexural slip folding and maintain a uniform thickness (Figure 33). However at the contact with the Rockdale Run Formation are shaly beds and thin beds of limestone. The shaly beds have flowed and faulted, and the intervening thin limestones are folded independently at a smaller scale than the massive underlying Stonehenge carbonates (Figure 33).

To facilitate analysis of folds in different structural and lithic domains stereograms of bedding normals (π diagrams) have been constructed and contoured. Diagrams A, B, C, and D (Figure 34) from the carbonate terrain indicate that the folds are cylindroidal. However, the non-uniform distribution of values along the stereonet great circle departs somewhat from the uniform distribution expected in an ideal concentric fold. This is a reflection of the regional structural assymmetry. Subvertical to overturned west-facing anticlinal limbs are the major limbs and upright east-dipping, east-facing anticlinal limbs are the minor limbs. Most of the statistical points therefore represent measurements on the major limb.

Diagrams E, F, G, and H (Figure 34) from the Martinsburg terrane show a poorly defined great circle with a maximum at each side near the primitive circle. This indicates that the folds are cylindroidal and nearly isoclinal with subvertical limbs. The absence of readings indicating horizontal or

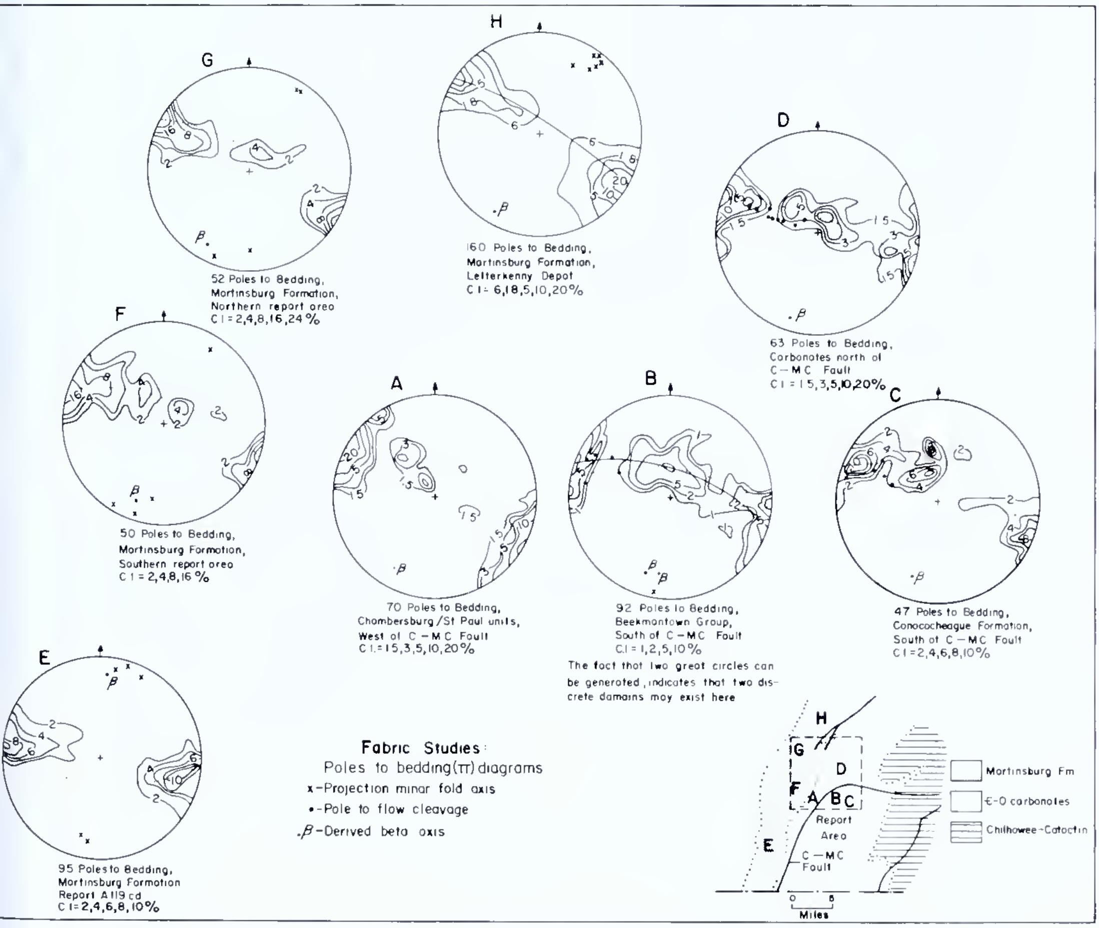

G
52 Poles to Bedding, Martinsburg Formation, Northern report area C I = 2,4,8,16,24 %
H
160 Poles to Bedding, Martinsburg Formation, Letterkenny Depot C I = 6,18,5,10,20%
D
63 Poles to Bedding, Carbonates north of C – M C Fault C I = 1.5,3,5,10,20%
F
50 Poles to Bedding, Martinsburg Formation, Southern report area C I = 2,4,8,16 %
A
70 Poles to Bedding, Chambersburg/St Paul units, West of C – M C Fault C I = 1.5,3,5,10,20%
B
92 Poles to Bedding, Beekmantown Group, South of C – MC Fault C.I = 1,2,5,10%
The fact that two great circles can be generated, indicates that two discrete domains may exist here
C
47 Poles to Bedding, Conococheague Formation, South of C – MC Fault C I = 2,4,6,8,10%
E
95 Poles to Bedding, Martinsburg Formation Report A119 cd C I = 2,4,6,8,10%
Fabric Studies:
Poles to bedding (π) diagrams
x – Projection minor fold axis
• – Pole to flow cleavage
.β – Derived beta axis
H
G
D
F
A
B
C
E
Report Area
C – MC Fault
0 5
Miles
Martinsburg Fm
Є-O carbonates
Chilhowee-Catoctin

Figure 34. Equal-area projections of poles to primary bedding.

gently inclined beds may be a function of this unit not cropping out well at these inclinations or it may be due to structural asymmetry of the type noted in the preceding paragraph.

Joints

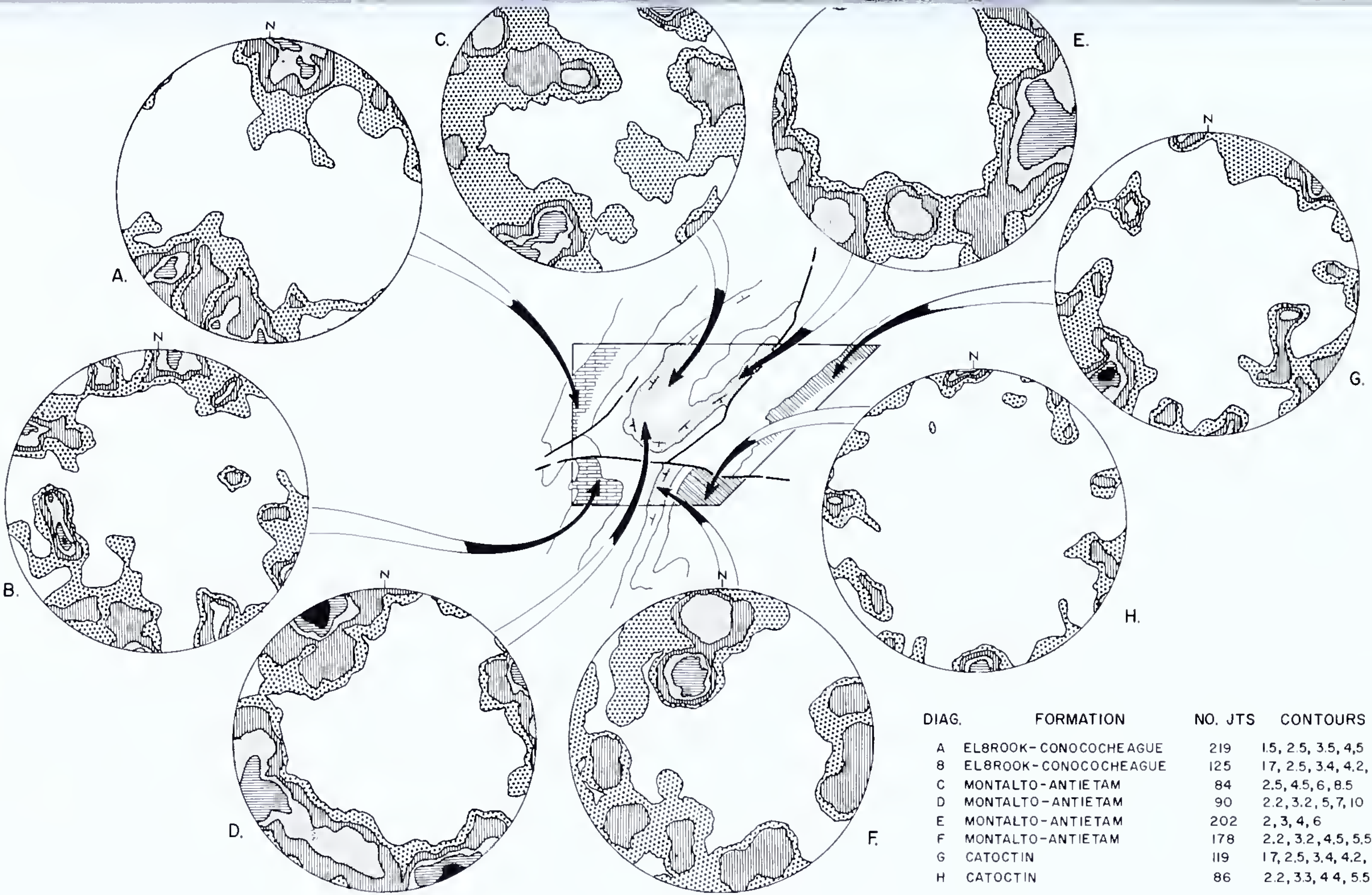
Because of their local importance in engineering and environmental geology as well as structural significance, joints are considered in this report. Much local information is available on joints in the Martinsburg, however little quantitative information is available from the carbonates.

Joints in the carbonate terrane were examined regionally by Cloos (1947, p. 898-900) under the general category of fractures. In summary, he recognized tension joints both normal to fold axes and to lineations, as well as joint systems that are acutely bisected by either the fold axis or lineation in *a*. Thus there are six major joint directions and each may show secondary and small fractures as associated feather joints. Tension joints normal to the fold axes (*ac* joints) are largely vertical or dip steeply, strike northwest, tilt in response to plunge of the folds, and are very common. Tension joints normal to lineation in *a* (*bc* joints) are also common. They parallel the strike of axes and dip northwestward about normal to lineation. Joint systems, or shear joints commonly intersect at about 60° in sets bisected by both *a* and *b*. It was concluded that joints formed slightly later in time than ooid extension and in the same tectonic deformation plan.

In a study of joints immediately to the east, in the Caledonia Park area Fauth (1968, p. 59) recognized various combinations of dip, strike, and oblique joints. However, most plots of data in pole joint diagrams (Figure 35) fail to clearly define prefential orientations; but they do show that most of the joints have a near vertical attitude, and that there is a definite absence of joints with an attitude near bedding. Figure 35 shows joint pole projections (Fauth, 1968) from mapped Elbrook and Conococheague Formations north and south of the Carbaugh-Marsh Creek fault. North of the fault there appears to be a well defined double maxima that may indicate a joint set bisecting the *ac* direction. South of the fault the girdle is more diffuse and there appears to be at least 5 systems of maxima, indicating overlap of several different joint sets (Fauth, 1968).

Joints measured in the carbonates on Letterkenny Depot do not show any statistically preferential orientation (Figure 36, A). Possibly, a greater number of measurements would define some orientation but in light of Fauth's data this does not appear likely.

Development of joints in the Martinsburg terrane differs considerably from those in the carbonate terrane. Figure 36 is a pole plot of joints in the Martinsburg in the mapped area and in the Letterkenny Army Depot immediately to the north. In both areas it is apparent that there is only one, extremely pronounced, maximum. This reflects a subvertical joint set that



DIAG.	FORMATION	NO. JTS	CONTOURS %
A	ELBROOK-CONOCOCHEAGUE	219	1.5, 2.5, 3.5, 4,5
B	ELBROOK-CONOCOCHEAGUE	125	17, 2.5, 3.4, 4.2, 5
C	MONTALTO-ANTIETAM	84	2.5, 4.5, 6, 8.5
D	MONTALTO-ANTIETAM	90	2.2, 3.2, 5, 7, 10
E	MONTALTO-ANTIETAM	202	2, 3, 4, 6
F	MONTALTO-ANTIETAM	178	2.2, 3.2, 4.5, 5.5
G	CATOCTIN	119	17, 2.5, 3.4, 4.2, 5
H	CATOCTIN	86	2.2, 3.3, 4 4, 5.5

Figure 35. Equal-area joint pole projections, Caledonia Park area (from Fauth, 1968 Figure 10).

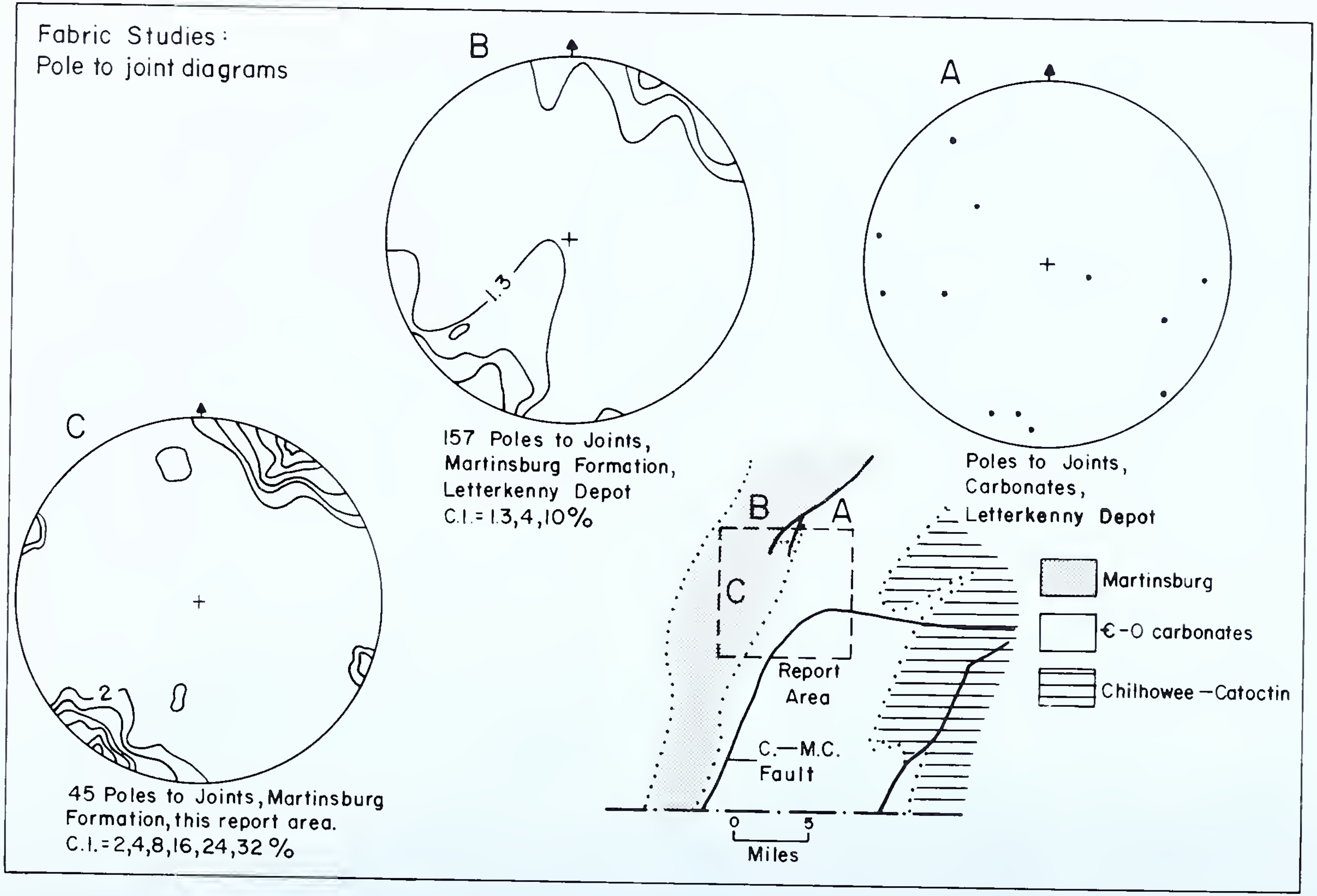

Fabric Studies:
Pole to joint diagrams
B
1.3
157 Poles to Joints, Martinsburg Formation, Letterkenny Depot
C.I. = 1.3,4,10%
A
Poles to Joints, Carbonates, Letterkenny Depot
C
2
45 Poles to Joints, Martinsburg Formation, this report area.
C.I. = 2,4,8,16,24,32 %
B
A
C
Report Area
C.—M.C. Fault
0
5
Miles
Martinsburg
Є-O carbonates
Chilhowee—Catoctin

Figure 36. Equal-area joint pole projections terrane of Martinsburg Formation.

trends N50°W, rigorously parallel to the transport direction as defined in π diagrams (Figure 34). This joint set is well developed in all lithologies of the Martinsburg Formation and spaced from several inches to a few feet. It is surprising that there does not appear to be a joint set parallel to the *b* axes. However, a pervasive fracture cleavage parallel to *b*, as a consequence of flexural slip folding, may obscure any jointing parallel to *b*.

In some of the massive graywacke beds in the Martinsburg (Figure 27) there is locally developed a bed normal jointing less systematically related to the regional stress.

Cleavage

Both flow cleavage (Figure 37) and fracture cleavage (Figure 38) are recognized in the mapped area. Cloos (1947) reported in detail on the development of flow or axial plane cleavage (S_1) in the South Mountain anticlinorium. He also (1951, p. 156) discussed fracture cleavage in the Massanutten synclinorium.

Flow cleavage is best developed in the Catoctin volcanics, in the core of the anticlinorium, and is shown by intense streakiness and elongated chlorite blebs and amygdules. The development and intensity of flow cleavage decrease progressively westward and in the mapped area is both sparse and subtle. Actually no flow cleavage was observed in rocks younger than the Beekmantown.

South of the Carbaugh-Marsh Creek fault, plots of S_1 poles in π diagrams (Figures 34, B, C, D) indicate *ac* directions of N64°W and N66°W which are within 4°-8° of being normal to derived β of diagrams B and C. North of the fault the *ac* direction is indicated by S_1 pole plots of N72°W and within 2° of being normal to the derived β of the π diagram D. From the few points in these diagrams it appears that regionally cleavage is about parallel to fold axes.

In a few places it is possible to demonstrate considerable fanning of S_1 about folds. One such place is about 4,500 feet south of Green Village (Plate 1) where an overturned anticline, with a width of probably a few thousand feet, is developed in the Rockdale Run Formation. The inverted limb dips east at 67° and S_1 at 20°; the upright limb dips east at 30° and S_1 at 63°. Thus S_1 fans out with a divergence of about 45°, opening to the northwest. Figure 39 shows fanning of S_1 about a small fold in the Zullinger Formation.

Some fracture cleavage is also developed in the carbonate terrain, on small folds in brittle dolomite beds. The folds in the road cuts at Scotland are excellent examples of this phenomenon which is only developed locally.

Fracture cleavage is abundant throughout the Martinsburg. Cloos (1951) also locally recognized flow cleavage—and indeed at times it is difficult to distinguish the two especially in fold hinges. In small outcrops composed principally of shale fracture cleavage is commonly expressed by a subvertical

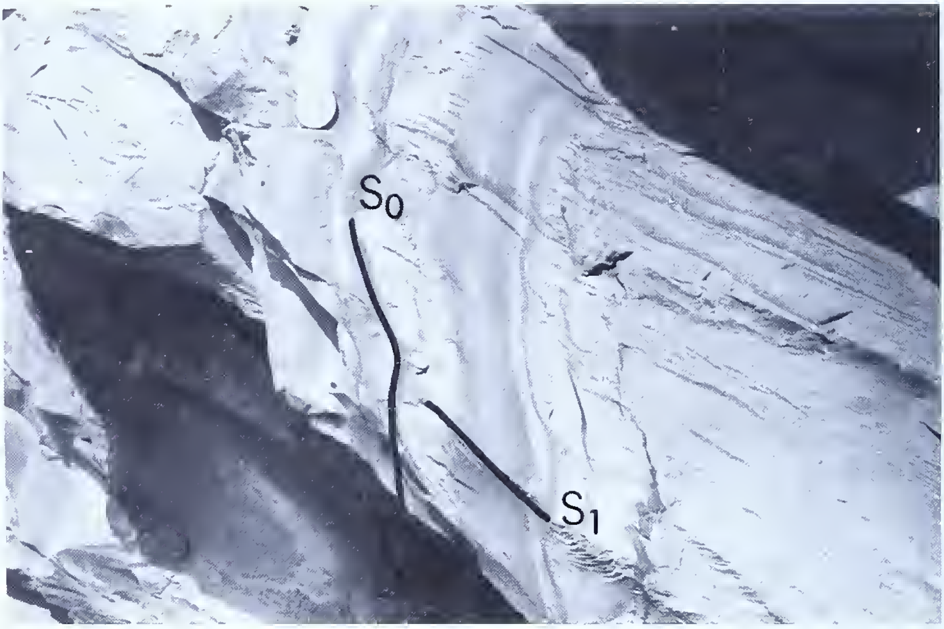


Figure 37. Intersection of primary bedding and flow cleavage (So × S_1). Zullinger Formation at Scotland.

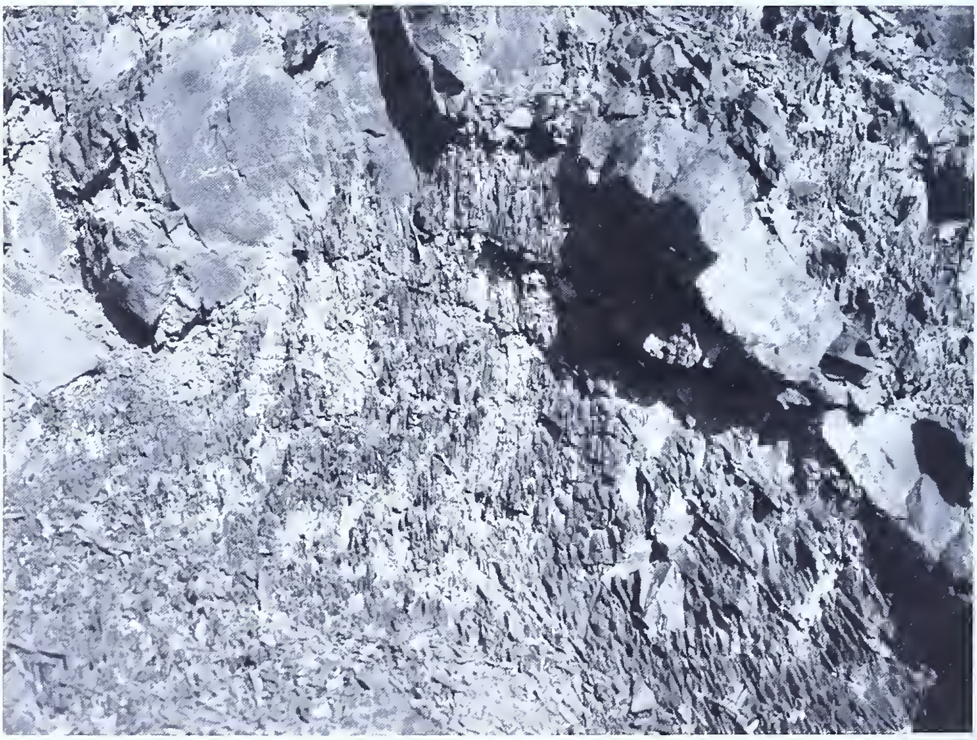


Figure 38. Anticline formed by flexural slip. Vertical fracture cleavage in fold hinge parallels axial plane, Martinsburg Formation.

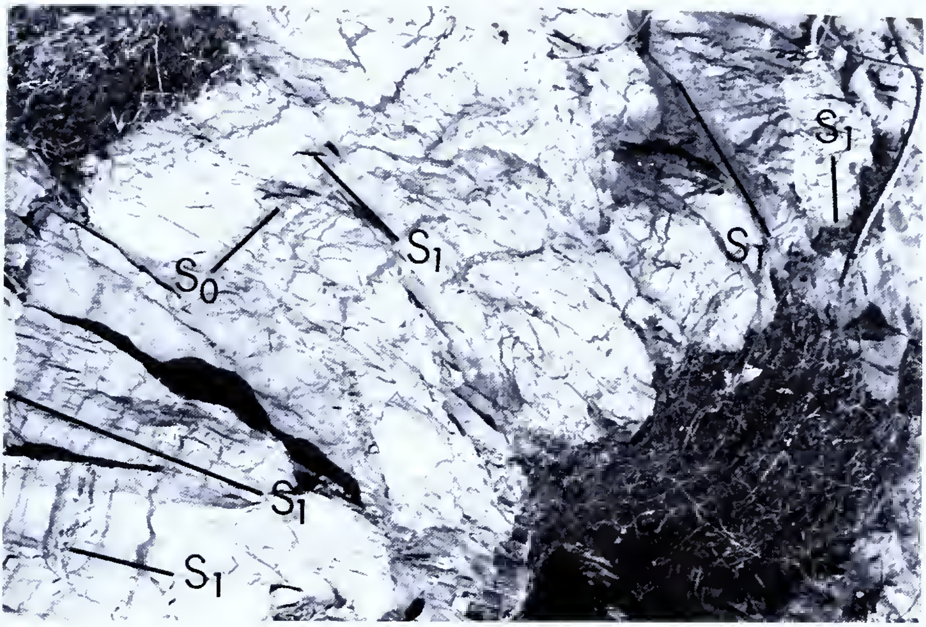


Figure 39. Fanning of flow-cleavage (S_1) about a small fold in the Zullinger Formation at Scotland.

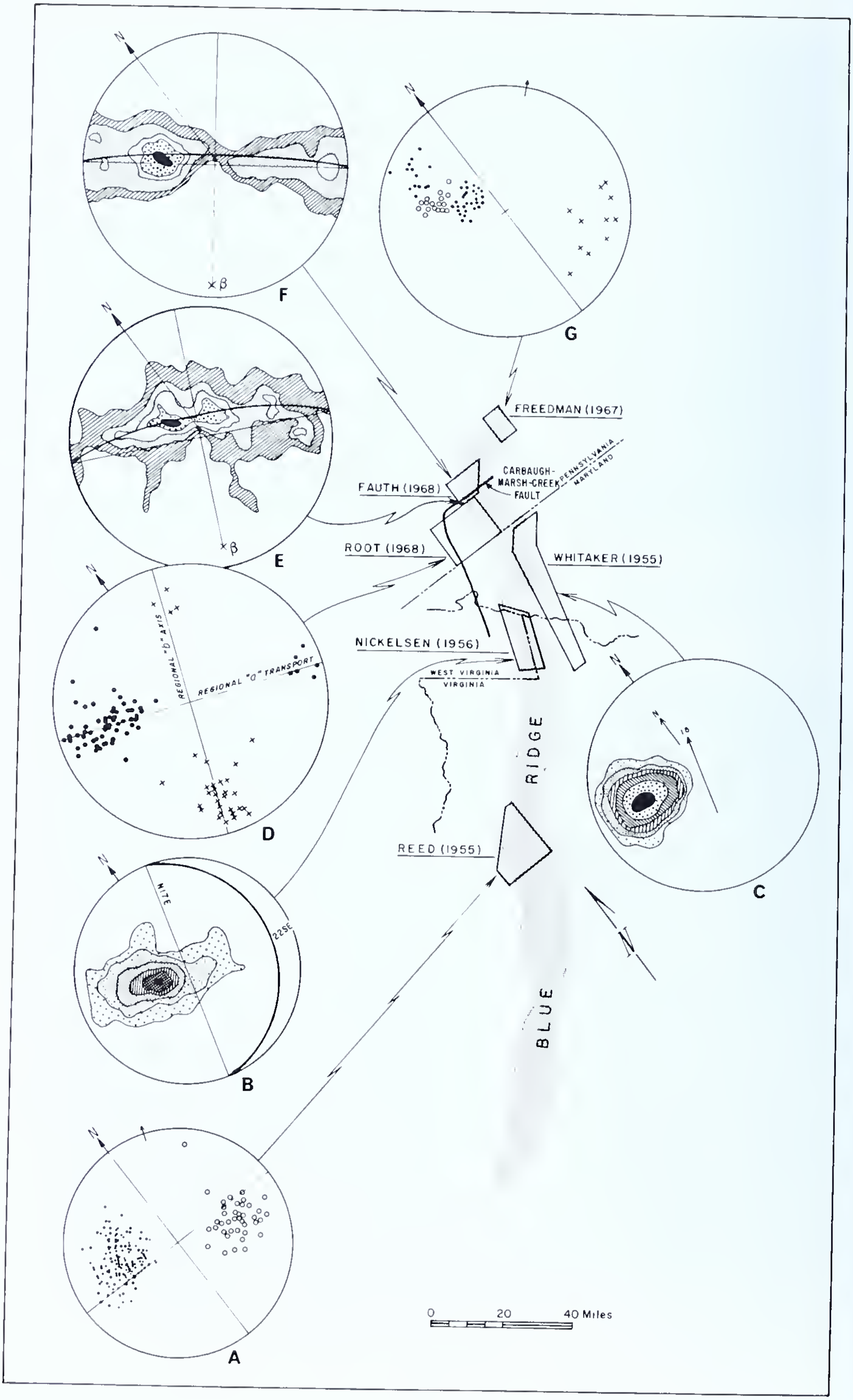
closely spaced cleavage (Figure 38) that yields pencil-shaped rock fragments. The orientation is due to the fact that fold limbs, as shown in π diagrams (Figure 31), are generally semi-isoclinal and the axial surface is vertical—the fracture cleavage consequently parallels the fold axis. In sequences with rocks of differing ductility some fracture cleavage fans about the fold in response to intrastratal slip between the beds. Some of the fanning may be due to rotation of early formed incipient bed-normal joint system.

STRUCTURAL SYNTHESIS

As has been shown by Cloos (1947, 1951) and Root (1968), and also in this report, the structural features form a relatively elementary pattern despite the geologic complexity of the region. Cleavage, folds, and faults generally develop normal to the transport direction.

The major interruption to this systematic pattern is the Carbaugh-Marsh Creek fault. Folds and faults cannot be matched across this fault (Plate 1, Figures 30 and 31). Also, there is a deflection in regional structural trend across the fault.

The deflection in structural trend is abrupt in rocks that form the core of the South Mountain anticlinorium. From Luray, Va. to the Carbaugh-Marsh Creek fault measurements of various structural elements (Figure 40), principally in the Catoctin-Chilhowee rocks, define a rectilinear structural grain of about N20°E. North of the fault, the structural grain abruptly


N
× β
F
N
G
FREEDMAN (1967)
N
× β
E
CARBAUGH-
MARSH-CREEK
FAULT
PENNSYLVANIA
MARYLAND
FAUTH (1968)
ROOT (1968)
WHITAKER (1955)
N
REGIONAL "b" AXIS
REGIONAL "a" TRANSPORT
D
NICKELSEN (1956)
WEST VIRGINIA
VIRGINIA
RIDGE
N
N
18
C
REED (1955)
N
N17E
22SE
B
N
BLUE
N
A
0 20 40 Miles

changes to N40°E—N45°E and persists to Mt. Holly Springs (Figure 40). This relationship is especially well established by Fauth (1968, Figure 11 G, H) who measured structural elements both north and south of the fault and showed that it was a line of deflection between regional trends (Figure 40).

This mapped area lies athwart the area of deflection of the structural grain. However, the deflection seems to be distributed with a broad zone rather than across a sharp line as in the core of the anticlinorium. Structural grain in the carbonates south of the Carbaugh-Marsh Creek fault (Figure 34, B,C) is N20°E. Immediately west of the fault it is N27°E (Figure 34, A), and immediately north of the fault it is N20°E (Figure 34, D). Structural grain in the Martinsburg terrane swings from N20°E to N30°E and N32°E from south to north across the area of deflection (Figure 34, E,F,G,H). The Pinola fault trends about N50°E and is a reflection of the regional structural grain in this domain. The change in structural trend through a broad zone may be due to the greater distance of this domain from the point of sharpest deflection across the fault in the core of the anticlinorium.

The inability to match structures across the Carbaugh-Marsh Creek fault is important in determining the origin of this feature. It is not that the structures are considerably offset, as nowhere across the approximately 2½ miles of right lateral displacement can structures be matched. Thus folding and faulting must have occurred independently across the fault, a conclusion

Figure 40. Petrofabric summation of Blue Ridge structures from Virginia to Pennsylvania and area studied by various individuals. Stereonet A from Reed (1955, Figure 6), equal area projection of a lineations (open circles) and poles of cleavage (solid dots) define a trend shown by arrow, of about N17°E in the Catoctin Formation. Stereonet B from Nickelsen (1956, figure 4a) based on 375 observations of poles to unfolded flow cleavage from all formations, contours ½—2—5—10—15—25%. Stereonet C from Whitaker (1955, Figure 4b) poles of 506 flow cleavage planes plotted from south of Owens Creek; general trend N15°E, average dip of flow cleavage 50°E, maxima 3—7—10—13—15—17%, data from all formations. Stereonet D from Root (1968, Figure 32), dots are poles to flow cleavage, crosses are projections of measured folds, and stars are projections of mineral smear lineations, data from carbonates only. Stereonet E from Fauth (1968, Figure 11e) 179 poles to bedding in area south of C.-M.C. fault with contours 1.1—2.8—4—5.5—6.7%, data from Chilhowee Group. Stereonet F from Fauth (1968, Figure 11g), 428 poles to bedding in area north of C.-M.C. fault with contours 1.3—2.5—5—6.6—10%. Stereonet G from Freedman (1967, plate 2, Figure 1) solid dots are poles to flow cleavage, open circles poles to bedding, and crosses are ac lineation, arrow defines tectonic trend, data from Chilhowee Group.

also reached by Fauth (1968). Therefore, the tear fault segment probably developed during earliest folding, but as it everywhere truncates folds and faults it was active during latest deformation also. Probably the many folds and faults on the plate bounded on the west by the Carbaugh-Marsh Creek fault and on the east by the Antietam Cove fault developed during westward translation and shortening of the plate. The fewer folds and faults north of the fault are the consequence of lesser westward translation and shortening of this block.

Refolded folds, folded cleavage, and generation of secondary and tertiary cleavages of the type that clearly demonstrate multiple deformations in the Piedmont region (Freedman and others, 1964) or the Lebanon Valley nappe (MacLachlan and Root, 1966) have no analogues in South Mountain. Several homoaxial events within a single period of deformation were recognized in the carbonates (Root, 1965). These include initial folding with movement of material out of the synclines onto the anticlinal crests, followed by a period of closer folding and thrusting from the east. In deformation involving the Chilhowee-Catoction units, Fauth (1968, p. 88-92, Fig. 17) recognized five phases including a terminal phase involving local development of a slip cleavage. Nickelsen (1956) and Freedman (1967) also observed, in incompetent beds, a later slip-cleavage development that crinkles the more pervasive flow cleavage.

The local development of slip cleavage is the only tectonic feature, recognized by these workers, that might indicate multiple deformation in South Mountain. However, Nickelsen (1956, p. 268) concluded that the stress orientation did not change from the development of flow cleavage to the development of the later slip cleavage. In the absence of any compelling evidence to the contrary it is, therefore, concluded that there is a single period of deformation in the South Mountain anticlinorium.

In Pennsylvania rocks of Precambrian to Ordovician age are harmoniously folded into the South Mountain anticlinorium. Farther south rocks as young as Devonian age have been folded into the Massanutten synclinorium which presumably is a result of the Blue Ridge deformation. Regionally the Appalachian Mountain Section of the Valley and Ridge Province includes sediments of Cambrian to Pennsylvanian age which seems to be entirely conformable and to have been deformed together in an Alleghanian, or late Paleozoic, movement (Rogers 1967, p. 417).

On the west side of the Great Valley in Pennsylvania, Pierce and Armstrong (1966) dated mylonite from a possible decollement zone in the Martinsburg by the K-Ar whole-rock method. An age of 340 m.y. or an Acadian orogenic date was obtained by this technique on the mylonite. This is probably reflected by some tectonic activity in the nearby Blue Ridge. If this date is reliable, it would appear that deformation in the Blue Ridge began in the Devonian.

Recent work by Rankin and others (1969) on isotopic age determinations of the Catoctin Formation, and its equivalents to the south, yields additional information on the age of Blue Ridge deformation. Zircons from the metarhyolites indicate an original age of 850 m.y., however, they also determined a lead loss of 230 m.y. which they judge to be an episodic loss. They conclude that the lead loss is compatible with a terminal Paleozoic Alleghanian event of major thrusting in the Blue Ridge. In summary then, both field and radiometric relations indicate major Alleghanian orogeny and possible minor Acadian movement in the Blue Ridge. No older orogeny is recognized.

The following summary represents the chronologic sequence of deformation events in this region: 1) Gentle folding and thrusting out of the Massanutten synclinorium, on west dripping thrusts, onto the South Mountain anticlinorium. Only rocks at about the carbonate-shale interface are involved. Thrusts limited by earlier east-west cross fault related to tear fault segment of Carbaugh-Marsh Creek fault. 2a) Development of the Carbaugh-Marsh Creek fault; westward translation and shortening of the South Mountain anticlinorium and development of the related strike slip Antietam Cove Fault. 2b) Development of folds and faults on the Carbaugh-Marsh Creek thrust plate and overriding and oversteepening of original thrusts out of the syncline. 2c) Development of flow cleavage and later fanning of flow cleavage as the folds are more appressed. Probably development of fracture cleavage in the Martinsburg at this time or slightly earlier. The events in stage 2 probably are synchronous in large part. 3) Development of *ac* joints in the Martinsburg.

It should be emphasized that the time differences involved are probably slight and that the deformational sequence is part of a single continuous orogeny. However, until independent dating of these events demonstrates a single orogeny the remote possibility should be considered that these may be products of multiple orogenies.

MINERAL RESOURCES

INTRODUCTION

Mineral production in Franklin county in 1968, for stone, plus sand and gravel amounted to about $1,666,000 in value. In the area of this report limestone, dolomite, and shale, are the rock types present. One of the purposes of the report is to point out the mineral potential of such rocks. The mineral resources of southeastern Franklin County is discussed in detail by Root (1968).

PRESENT POTENTIAL

The common use of most of the minerals in the area will be considered in the light of their local geologic conditions.

Magnesium and Magnesium Compounds

Dolomite is used for the production of magnesium metal, and magnesium compounds such as refractory magnesia, basic magnesium carbonate, or magnesium chloride (Table 1). No rigid specifications exist for dolomite for these purposes but generally it should contain more than 40 percent $MgCO_3$ and less than 1 percent each of SiO_2, Fe_2O_3, and Al_2O_3.

Table 1. *Chemical requirements for uses of limestone and dolomite**

Use	*Chemical requirements*
Limestone for Portland cement	Magnesium carbonate ($MgCO_3$) not more than 6.3%. Minimum calcium carbonate ($CaCO_3$) content varies from plant to plant depending on the availability of other raw materials.
Limestone for lime (high calcium)...	Calcium carbonate ($CaCO_3$) content not less than 97%, preferably 98% or more.
Magnesium carbonate for lime (magnesium)	Magnesium carbonate content should be between the limits of 21 and 31.5%.
Limestone and magnesian limestone for steel flux (blast furnaces)	Silica (SiO_2) less than 5% Alumina (Al_2O_3) less than 2%. Magnesium carbonate less than 8% to less than 31%. Phosphorus content should not exceed 0.01%.
Limestone for steel flux (open hearth)	Calcium carbonate ($CaCO_3$) content should exceed 98% but some limestone as low as 97% $CaCO_3$ is sometimes accepted.
Dolomite for refractories..........	Magnesium carbonate ($MgCO_3$) not less than 37.5%. Silica (SiO_2), ferric oxide (Fe_2O_3) and alumina (Al_2O_3) not to exceed 1% each.
Limestone for general chemical use..	Calcium carbonate ($CaCO_3$) content should exceed 98% but limestone as low as 97% $CaCO_3$ is sometimes used.
Agricultural limestone............	Minimum of 85% $CaCO_3$.
Agricultural dolomite............	Calcium-magnesium carbonate content should total at least 85%.
Limestone and dolomite for glass....	Ferric oxide (Fe_2O_3) not more than 0.05%. Calcium carbonate ($CaCO_3$) content should exceed 98% of limestone, or 98% calcium-magnesium carbonate, in case of dolomite.
Limestone for paint and filler.......	In general the calcium carbonate content should exceed 96% but the magnesium carbonate ($MgCO_3$) no greater than 1%. Other maxima are Fe_2O_3—0.25%, SiO_2—2.0%, and SO_3—0.1.

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* This table indicates chemical requirements as standardized by the various consuming industries.

In this report area only the Pinesburg Station Formation contains abundant amounts of dolomite. However, there is a progressive increase in the number of limestone interbeds (Plate 3) in this area from the nearly wholly dolomite sequence to the south (Root, 1968). There is a zone about 90 feet thick (Plate 3 and Units 108-112, Locality 3, Appendix) in the lower part of the Pinesburg Station composed entirely of dolomite so that selective mining would not be necessary. A naturally mixed dolomite-limestone product can be mined directly from either the upper Rockdale Run or Pinesburg Station beds.

Four chemical analyses (Table 2) from the Pinesburg Station dolomites to the south near Marion indicate that from 2 to 10 percent SiO_2 is present in the dolomite. As much as 20 percent acid insoluble residues are present in samples from southeastern Franklin County (Root, 1968).

A complete section of the Pinesburg Station Formation and the associated upper part of the Rockdale Run Formation and lower part of the St. Paul Group was analyzed thoroughly to determine the composition of the rock as reflected by the amount of acid insoluble residue (Plate 2). Acid insoluble residue reflects the amount of SiO_2, Al_2O_3 and Fe_2O_3 in the rock. As a rule of thumb, based on chemical analyses in Franklin County, the ratio of SiO_2 to $Al_2O_3 + Fe_2O_3$ is about 3:1. Results are presented in Plate 2. The acid insoluble residue content of the various formations in this report area are shown on a histogram diagram (Figure 41).

Table 2. *Partial chemical analyses of Beekmantown Group dolomites in southeastern Franklin County*

Sample	*1*	*2*	*3*	*4*
SiO_2	2.16%	5.39%	9.68%	6.68%
Al_2O_3	0.67	0.99	1.76	1.23
Fe_2O_3	0.32	0.51	0.92	0.58
P_2O_5	0.01	0.02	0.03	0.23
S	0.01	——	——	——
$CaCO_3$	63.02	64.38	51.23	59.78
$MgCO_3$	32.47	27.47	33.53	29.65

1. Zone 30′ thick at top of Rockdale Run Fm., Kauffman, Pa. section. After Swartz & Thompson (1958).
2. Zone 40′ thick below sample 3.
3. Zone 40′ thick below sample 4.
4. Zone 40′ thick at top of Rockdale Run Fm., Marion, Pa. section. After Swartz & Thompson (1958).

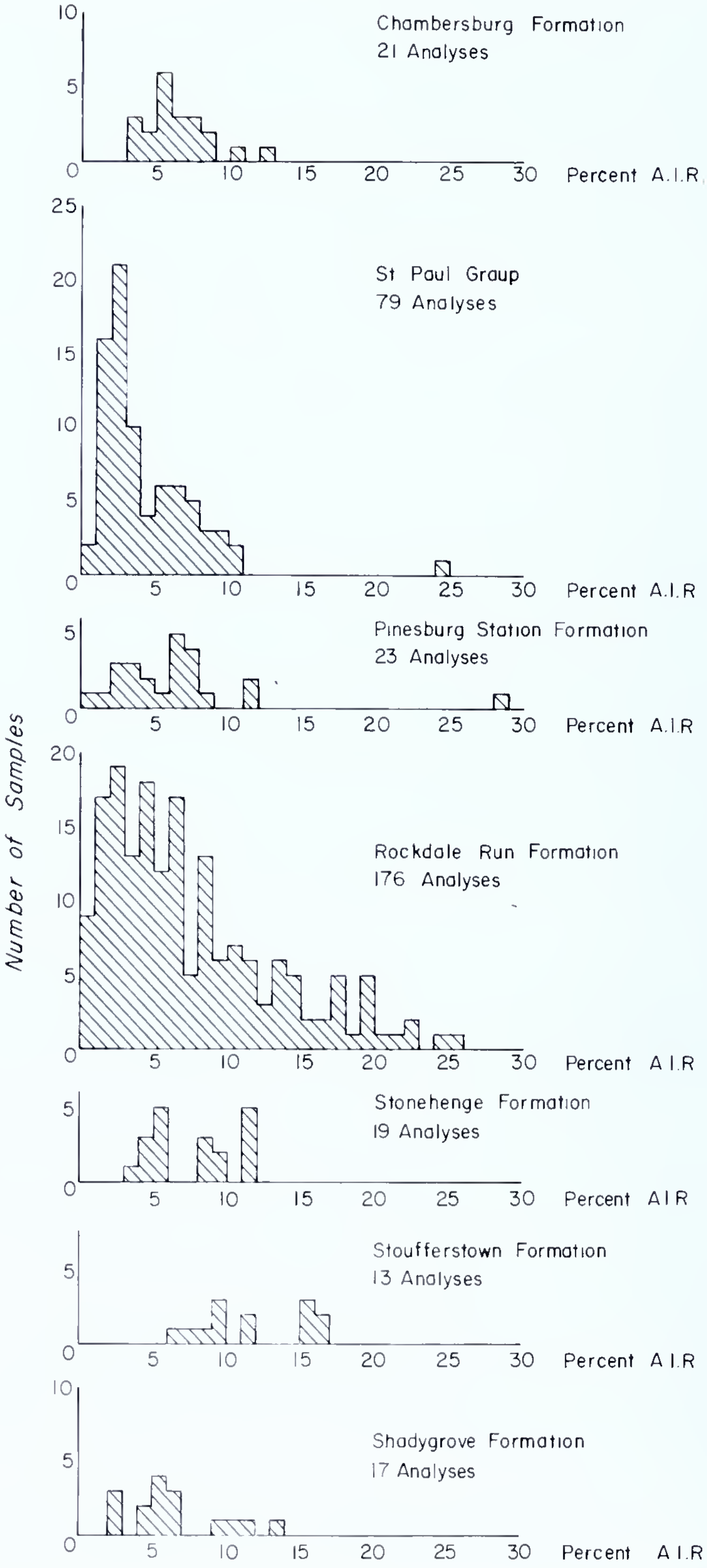

Figure 41. Percent acid insoluble residue by formation in report area.

The basal 150 feet of the Pinesburg Station is nearly wholly dolomite; and, based on 16 samples, averages 5.2 percent acid insoluble residue. Dolomite interbeds in the underlying Rockdale Run Formation, although numerous, are only a few feet thick; and based on 32 samples, they average 6.1 percent acid insoluble residue. The few dolomite interbeds present in the basal St. Paul Group average 12.9 percent acid insoluble residue. Chert is a common constituent of these rocks and is deleterious both in quality control of the product and in the milling operation. From these data it would appear that the massive dolomites of the Pinesburg Station and thinner dolomites of the other formations are not suitable for purposes requiring a low silica content (Table 1).

To the south, in West Virginia, Grimsley (1916, p. 35) reports $MgCO_3$ of about 36 to 41 percent and SiO_2 content of from 1.8 to 6.0 percent from 6 samples of what is the Pinesburg Station Formation. Near Winchester, Virginia, Edmundson (1945, p. 37) reports 40 percent $MgCO_3$, 5.3 percent SiO_2 and 1.2 percent combined Al_2O_3 and Fe_2O_3 from 350 feet of dolomites from the Pinesburg Station Formation. Thus for a considerable distance along the Great Valley it lacks certain economic utility and there is no indication that the grade of dolomite improves to the north.

Dolomite of the Pinesburg Station Formation meets the requirements for agricultural dolomites. The principal requirements for a rock of this type (see Table 1) are that $CaCO_3$-$MgCO_3$ should total 85 percent, apparently SiO_2, Al_2O_3, and Fe_2O_3 content is not important. As the Pinesburg Station dolomites and associated dolomites at the top of the Rockdale Run Formation are normally more than 90 percent carbonate (Table 2) they fulfill the necessary requirements.

Chemical Grade Limestone

High calcium limestones are used in diverse ways. Portland cement, lime, steel fluxstone for open hearth and blast furnace, general chemical use, glass manufacture, paint filler, and agricultural limestone are but some of the common uses of high calcium limestone. Chemical requirements of the limestone utilized in these industries is summarized in Table 1. For uses such as high calcium limestone, steel fluxstone, chemicals, glass, and paints and filler, the $CaCO_3$ should be in excess of 90 percent and the SiO_2 correspondingly low.

The St. Paul Group limestones have historically been the source of chemical grade limestones in the Cumberland Valley. No complete sections of the St. Paul are present in northeastern Franklin County, however a partial section of the upper part of the St. Paul was measured about 1 mile southwest of Chambersburg (Appendix, Locality 4). There is a fault present in the covered interval at unit 66 (Figure 42) which duplicates an unknown amount of the underlying section (units 67 to 99).

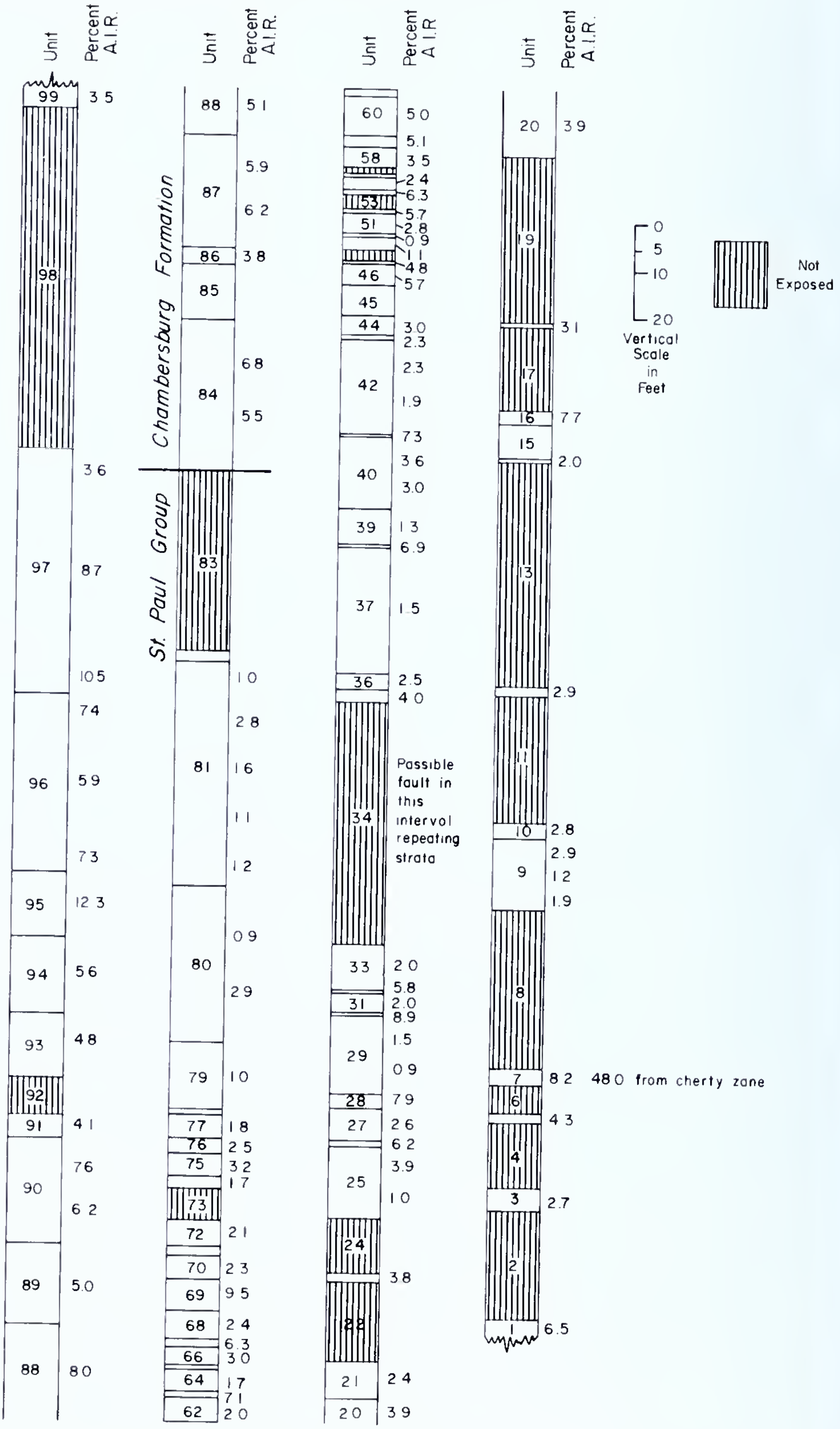

Figure 42. Vertical distribution of acid insoluble residue in the upper part of the St. Paul Group and lower part of the Chambersburg Formation.

The middle portion of the St. Paul, which is characterized by slightly nodular, thin-bedded, detrital-skeletal micritic limestone with chert nodules and silicified fossils (Figure 22), is not present in this measured section. It probably occurs below the lowest bed in the measured section. This part of the St. Paul Group is not deemed to be exploitable as the chert is a deleterious mineral in the extractive process.

The basal portion of the St. Paul is poorly exposed and cannot be evaluated quantitatively, but it does contain beds of micritic limestone (vaughanites of previous reports) that are of the same general quality as analyzed beds of high purity in the uppermost part of the St. Paul. This horizon was suitable for chemical grade limestones just to the south (Root, 1968), and it should be considered as a potential source of chemical grade limestone in this report as well.

A total of 71 samples were collected from the 790 feet of stratigraphic section measured in the St. Paul. The average amount of acid insoluble residue is 3.4 percent. The uppermost 130 feet of St. Paul (units 18 to 30, Figure 42) in this section average only 1.8 percent acid insoluble residue and thus meets the standards for manufacture of cement, steel fluxstone, high calcium limestone, and possibly limestone for general chemical use (Table 1).

The other formations in this report area contain too much SiO_2, Al_2O_3, and Fe_2O_3 to meet the requirements for high calcium limestone.

A total of 21 samples for the lower 380 feet of the Chambersburg Formation measured southwest of Chambersburg (Figure 42; Locality 4, Appendix) averaged 6.3 percent acid insoluble residue. On the basis of work to the south (Root, 1968) it appears that the upper part of the formation is equally high in insoluble residues and consequently limited to non-high calcium limestone use.

A considerable number of samples were collected from the Rockdale Run through to Shadygrove Formations approximately along the line of section where Sando (1958) measured these rocks near Chambersburg (Locality 2, Appendix). An additional collection was made in the upper part of the Rockdale Run section offset about ½ mile to the north to supplement the poor exposures in Sando's section. The results of these analyses are presented in the succeeding four paragraphs. Each analyzed sample is the composite of several smaller samples collected over an interval of a few feet. While this is not as significant as a channel sample it gives a fairly reliable estimate o the composition of each formation (Figure 43).

Eighty samples from the Rockdale Run Formation averaged 10.7 percent acid insoluble residue (Figure 43). Although a few of the samples contained only 3 percent acid insoluble residue, these do not appear to be thick zones (in excess of 100 feet) which could be selectively quarried for this moderately high calcium limestone.

Twenty samples collected from the Stonehenge Formation (Figure 43) average 7.9 percent acid insoluble residue. A few samples of fairly high purity, contained as little as 5 percent acid insoluble residue. A zone about 600 feet above the base of the Beekmantown (Figure 43), which could be as much as 100 feet thick averages about 5.0 percent insoluble material and merits additional investigation.

Fourteen samples, averaging 13.7 percent acid insoluble residue, were collected from the Stoufferstown Formation (Figure 43). A few thin beds contained as little as 4 percent acid insoluble residue but generally the residue content is too great for utilization as a high calcium limestone.

Acid insoluble residues from 16 samples of the upper two-thirds of the Shadygrove limestone average 5.9 percent. Locally some beds contain only 2 to 3 percent insoluble material (Figure 43). However, these beds are thin and as cherts and some quartzose sand bands occur sporadically throughout, this formation does not appear attractive as a source of high calcium limestone.

In addition to those above listed samples from Sando's (1958) measured section, samples were analyzed from the uppermost part of the Rockdale Run section at Harrison School (Locality 3, Appendix). The results of these analyses are presented in Plate 2. The limestones contained an average of about 3.0 percent acid insoluble residue, based on 56 samples. Dolomite interbeds which are prominent in this part of the Rockdale Run, contained an average of 6.1 percent acid insoluble residue based on 32 samples. Although several of the individual limestone beds contain less than one percent acid insoluble residue (Plate 3) the associated dolomite and limestone interbeds contain relatively large amounts of acid insoluble residue. Therefore selective quarrying would be necessary for a high calcium product and considering the relatively thinly interbedded nature of these rocks, such an operation is currently uneconomical.

Seven samples were collected randomly from a three hundred foot interval at the base of the Rockdale Run Formation at the quarry at New Franklin. This is part of the informal lower subdivision characterized by large pink chert nodules, marbleoid limestones with a pinkish cast, and massive beds of dove-colored stromatolite micritic limestone. These samples contained an average of 8.4 percent acid insoluble residue which was surprising because macroscopically they appear to be very pure; almost as pure in appearance as the "vaughnitic" micritic limestones of the St. Paul Group which are high calcium limestones.

Table 3 represents partial chemical analyses, by the operator, of 10 samples of the Stonehenge Formation collected across the south face of the Valley Quarries Inc. operation at New Franklin, about 4 miles south of the analyzed section near Chambersburg. The insoluble material averages 14.3 percent here with none less than 7.5 percent, indicating that to the south of Chambersburg (Figure 43) the Stonehenge Formation is slightly more impure.

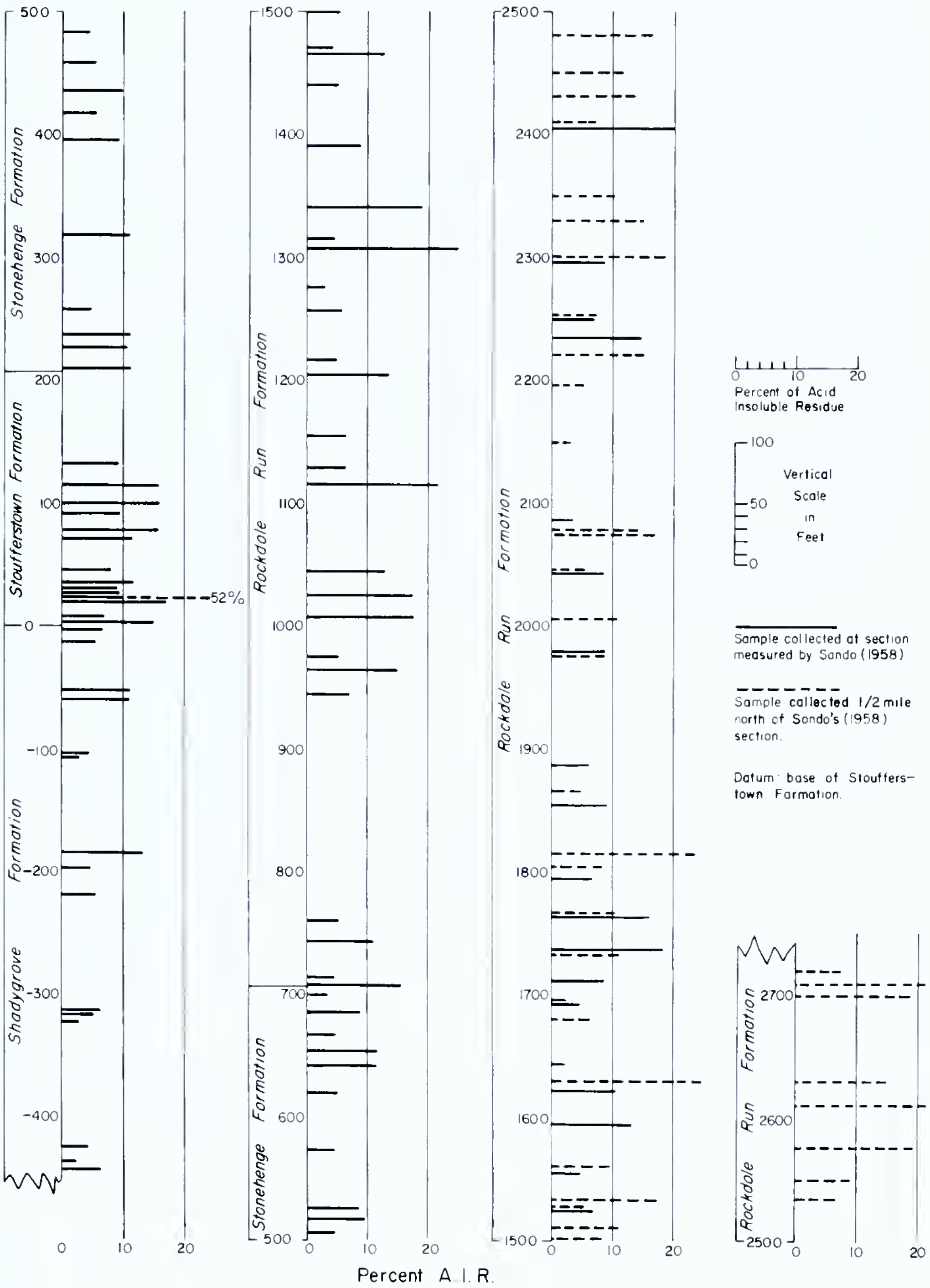

Figure 43. Vertical distribution of acid insoluble residue in the Shadygrove-Rockdale Run Formations.

Table 3. *Partial chemical analyses of Stonehenge Formation. Samples collected across south face of quarry at New Franklin.*

Sample	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SiO_2	5.46	9.62	11.60	10.50	8.26	15.06	13.66	17.88	7.80	7.06
Al_2O_3 Fe_2O_3 P	2.12	3.60	3.02	3.34	2.32	5.34	4.76	7.06	1.84	2.54
$CaCO_3$	90.25	81.50	81.47	78.50	82.15	73.47	75.58	68.00	88.07	87.32
$MgCO_3$	2.26	4.58	2.28	6.78	5.69	3.23	4.32	2.78	1.37	1.37

The Zullinger Formation was not sampled because studies in southeastern Franklin County (Root, 1968) demonstrate that this formation lacks potential for high calcium limestone. The Zullinger lithologies of this report area are identical to the cyclic lithologies immediately to the south. It is inferred that the acid insoluble residue content there, which averages about 15 percent, reflects the average residue content in the report area. Although some beds contain only 2 percent residue, these are generally too thin (less than 20 feet) to be selectively mined.

Impure Limestones

All of the formations except the St. Paul Group are composed of limestones that contain excessive amounts of SiO_2, Al_2O_3, and Fe_2O_3 for high calcium limestone utilization. There are several non-aggregate purposes in which these less pure limestones can be exploited.

Chemical requirements for Portland cement and agricultural limestone (Table 1) are attained by many of the units. By controlled mixing of shale and additives the Zullinger, Shadygrove, Stoufferstown, Stonehenge, Rockdale Run, and Chambersburg Formations are suitable as a limestone source for Portland cement. However, the variability in SiO_2, Al_2O_3, and Fe_2O_3, as reflected by the content of acid insoluble residues (Figures 41, 42, 43) of these formations, necessitates much quality control study of the limestones. These same units are all suitable for agricultural limestone which requires less quality control as the compositional standards are less rigorous than for Portland cement limestone. These rocks may also be blended with dolomite from the Pinesburg Station Formation to produce a magnesium agricultural product.

Calcareous marls occur at several places in the mapped area especially along some of the small creeks developed on limestone close to the Martinsburg shales. Although some deposits are of fair size and contain 85 to 90 percent $CaCO_3$ none has been exploited to date. These deposits are discussed by Miller (1934, p. 388).

Coarse Aggregate

Material classed as coarse aggregate by the Pennsylvania Department of Highways includes stone, gravel, and slag of which only the first is produced in Franklin County. To meet highway specifications stone, whether it be type A, B, or C, shall be prepared from tough durable rock, free from slaty texture or cleavage planes. Classification of stone is based primarily on weight loss during the Los Angeles Rattler test—the loss is progressively greater from type A to type C. In addition, more deleterious substances such as shale and clay lumps are permitted in type C than type A stone.

Two quarries in eastern Franklin County, the Valley Quarries, Inc. operation near New Franklin and the Appalachian Stone Division of Martin-Marietta Corp. near Zullinger, produced class A stone. The former produces from the Stonehenge Formation and the latter from the Zullinger Formation. Other quarries in the county that produce type A stone are located in the Chambersburg Formation and St. Paul Group. All the carbonate formations in the area above the Elbrook, should be capable of meeting requirements for type A stone. The basal part of the Rockdale Run locally has intercalated shale beds that decrease the soundness of the stone to type C. In addition, chert horizons at the base of the Rockdale Run, in the Shadygrove Formation, and the middle of the St. Paul Group might yield a type C rather than type A stone, as well as causing mechanical difficulty in the crushing operation.

Fine Aggregate

Material classed by the Pennsylvania Department of Highways as fine aggregate for use other than in bituminous mixtures, consists of hard, durable grains thoroughly cleaned by washing, free from lumps of clay and all vegetable and deleterious substances. Three categories: natural sand, manufactured sand, and artificial sand are recognized. Only manufactured sand which results from the controlled mechanical breakdown of conglomerate rock into its natural individual grain sizes is produced in the area. Fine aggregate is divided into types A, B, C, and D with type A containing less silt, possessing a greater strength ratio, and less percentage loss in soundness tests than types B, C, and D.

Some of the river gravels and sands (Plate 1) are capable of yielding both fine and coarse aggregate but to date they have not been prospected.

Dimension Stone

Under the category of dimension stone are included building stone, monumental stone, paving stone, curbing, and flagging. Physical properties to be considered are hardness and workability, strength, porosity and specific gravity, and durability. Other factors to consider are textures and color which influence the appearance of a rock. Utility of the rocks for dimension stone has been discussed by Stone (1932, p. 161-164). He cites the abundant local use of various limestone for building stone. In the writer's opinion many of the limestones have sufficient beauty and the physical requirements for a popular building stone of the ashlar type.

The reddish to light-gray marbleoid limestones at the base of the Rockdale Run Formation (Plate 1) and certain reddish marbleoid limestone horizons in the Zullinger Formation offer possibilities for an attractive monument stone or building stone. From observations in quarries the marbleoid limestones of the Rockdale Run Formation maintain these colors at depths and where free of chert nodules are in sufficiently thick beds so that large pieces could be quarried. Local shale intercalations at this horizon, however, might be a problem in quarrying.

Shales and Clay

Recent work by O'Neill and others (1965) has indicated potential utility of certain shales in Franklin County. This has led to an intensive investigation of properties and uses of shales by Karl Hoover and others of the Pennsylvania Geological Survey staff. Because of the important economic aspect of some shales, their findings are summarized in this report, but detailed information will be published at a later date.

On the basis of slow firing tests physical properties such as workability, plasticity, pH and soluble salt determinations, water of plasticity, drying and firing shrinkage, color (fired and unfired), percent cracking, apparent specific gravity, and hardness determine whether a clay is suitable for ceramic or nonceramic uses. Included under the ceramic category are clays used for whiteware, structural products, refractory products, artware or pottery, and lightweight aggregate. Included under the nonceramic category are clays used as filler or paint, plastics, paper, rubber, and clays used in oil clarifiers, abrasives, foundry molds, drilling muds, and pigments (O'Neill and others, 1965).

In eastern Franklin County the shales of the Martinsburg Formation have economic potential in ceramic use. Eleven samples of shale from the Martinsburg were collected throughout the area. Initial samples weighed 5 pounds and were tested by slow firing and then by quick firing. Those quick fired samples that showed good bloatability, which is indicative of lightweight aggregate potential, were recollected as 200-pound specimens. These larger samples were tested by the rotary kiln method to evaluate their use in lightweight aggregate. Results of the various tests are shown in Table 4. Chemical analyses of some of the shales are shown in Table 5. Location of all samples are listed in Table 4.

Results of these tests indicate that certain shales in the Martinsburg Formation have an excellent potential as lightweight aggregate. Some may also be used as face brick and floor tile. Undoubtedly other areas in the Martinsburg Formation contain shales suitable for lightweight aggregate and other ceramic products. Any areas that are to be developed should be thoroughly sampled and analysed prior to exploitation.

Table 4. *Test results of shales in the Martinsburg Formation.*

Sample	*Location*	*Potential uses*
1	In NE Williamson 8900′S of 39°52′30″ lat. 1700′W of 77°47′30″ long.	None (narrow firing range; short working properties negative preliminary bloating tests)
2	At Stone Bridge 7800′S of 39°52′30″ lat. 2300′W of 77°45′ long.	None (poor firing color, short working qualities, preliminary bloating test was positive but did not merit rotary kiln tests)
3	At Stone Bridge 7500′S of 39°52′30″ lat. 2500′W of 77°45′ long.	None (poor firing color, negative bloating test)
4	About 2.5 miles SE of Williamson 1400′S of 39°50′ lat. 3900′W of 77°45′ long.	Lightweight aggregate (best potential)
5	About 1.5 miles E of Upton 3350′N of 39°47′30″ lat. 7700′W of 77°45′ long.	Building brick (poor color, should fire to grade MW face brick at about 1950°F.)
6*	In SW Greencastle 1000′S of 39°47′30″ lat. 4600′E of 77°45′ long.	Lightweight aggregate (fair potential, good pore structure, satisfactory crushing characteristics, short firing range undesirable fragment shape)
7*	About 1 mile W of Greencastle 700′N of 39°47′30″ lat. 300′E of 77°45′ long.	Lightweight aggregate (fair to good potential, good pore structure, satisfactory crushing characteristics, undesirable fragment shape)
8	About 1.5 miles NW of Greencastle 7500′N of 39°47′30″ lat. 2300′E of 77°45′ long.	Face brick, floor tile
9	About 2 miles WNW of Kauffman 3000′N of 39°50′ lat. 2700′E of 77°45′ long.	Lightweight aggregate (fair potential, good pore structure, undesirable fragment shape, poor crushing character)
10*	About 1.3 miles NW of Marion 2500′S of 39°52′30″ lat. 2500′W of 77°42′30″ long.	Lightweight aggregate (good potential)
11	About 0.8 miles NW of Marion 4500′S of 39°52′30″ lat. 300′E of 77°42′30″ long.	Lightweight aggregate (fair potential, fair pore structure, excessive loss in crushing of raw materials)

* Chemical analyses listed in Table 5.

Table 5. *Chemical analyses of shales in the Martinsburg Formation.*

Sample #	*6*	*7*	*10*
SiO_2	64.10	66.00	69.00
Al_2O_3	14.00	12.00	11.60
Fe_2O_3	3.34	3.99	6.37
FeO	4.09	3.47	1.07
CaO	1.95	1.99	0.32
MgO	1.46	1.39	1.58
K_2O	3.30	3.20	3.00
Na_2O	1.58	1.65	0.95
TiO_2	0.83	0.85	0.80
L.O.I.	5.22	5.44	5.24
S	0.97	0.75	0.044
CO_2	1.54	1.36	0.37
Combined H_2O	—	—	—
H_2O 110° C	0.12	0.16	0.51
C	0.43	0.54	0.35
TOTAL	102.93	102.79	101.20

Ground Water

Since the early 1960's, because of drought conditions and the general increased demand of water for both industrial and domestic purposes, ground water has been of considerable importance in Franklin County. It has not been within the scope of this study to examine the ground-water resources of the county in detail; but, because of its importance, an attempt will be made to point out some geologic features related to groundwater accumulation.

A brief study of the water resources of Franklin County was made by Hall (1934, p. 171–177). His ratings of the water-bearing properties of various formations is shown in Table 6. A quantitative study of the Cambro-Ordovician carbonates and the Martinsburg Formation was made near Martinsburg, West Virginia, by Beiber (1961) whose results (Table 7) are somewhat at variance with those of Hall (1934) in that the Beekmantown Group is rated as an excellent aquifer, the Elbrook is rated as good, the Martinsburg is rated as fair, and the Chambersburg, St. Paul, and Conococheague Formations are rated as poor. It is felt that the small number of wells used in evaluation of the St. Paul do not accurately reflect the aquifer potential of this unit.

Records of water well drillers, as filed with the state in conjunction with the Water Well Drillers License Act, are an aid in assessing the ground water potential of an area. A total of 111 well records in eastern Franklin County contain information concerning yield and depth of various aquifers.

Table 6. *Water-bearing properties of various geologic units in eastern Franklin County. After Hall (1934).*

Geologic Name	*Water-Bearing Properties*
Martinsburg Formation	Small quantities of hard water at moderate depth.
Chambersburg Formation	Fair amounts of hard water.
St. Paul Group	Some larger springs and excellent wells. Hard water.
Beekmantown Group	Solid limestone yields little water but local solution channels yield large quantities hard water.
Conococheague Group	Not a good water horizon but wells encountering solution channels yield large quantities hard water.
Elbrook Formation	Poor water horizon. Hard water.

In the Martinsburg shale 52 completed wells have an average initial yield of about 18 g.p.m., and the average depth to the first show of water was about 50 feet. This initial yield is similar to that calculated by Beiber (Table 7). The histogram (Figure 44) shows the distribution of the initial yields.

In the carbonate terrain 59 completed wells have an average yield of about 16.5 g.p.m., and the average depth to the first show of water was 90 feet. This is similar to the yield noted by Beiber (Table 7) in the Chambersburg, St. Paul, and Conococheague units, but considerably less than the yields in the Beekmantown. The histogram (Figure 44) shows the distribution of initial water yields in the carbonates. The variation in drilled depth to water is considerably greater in the carbonates than in the shales. Some limestone

Table 7. *Yield and specific capacity of Cambro-Ordovician aquifers in Berkeley and Jefferson Counties, West Virginia. Data from Beiber (1961).*

General Well Data			*Drawdown Test*		
Geologic Unit	Average Yield (g.p.m.)	No. Wells	Median Yield (g.p.m.)	Median Spceific Capacity g.p.m./ft. Drawdown	No. Wells
Martinsburg	21	35	21	8	8
Chambersburg	18	11	18	5.1	3
Saint Paul	16	3			
Beekmantown	69	55	200	5	7
Conococheague	16	24	14	.5	7
Elbrook	26	12	17	2.2	5
Waynesboro	26	9	20	4	3

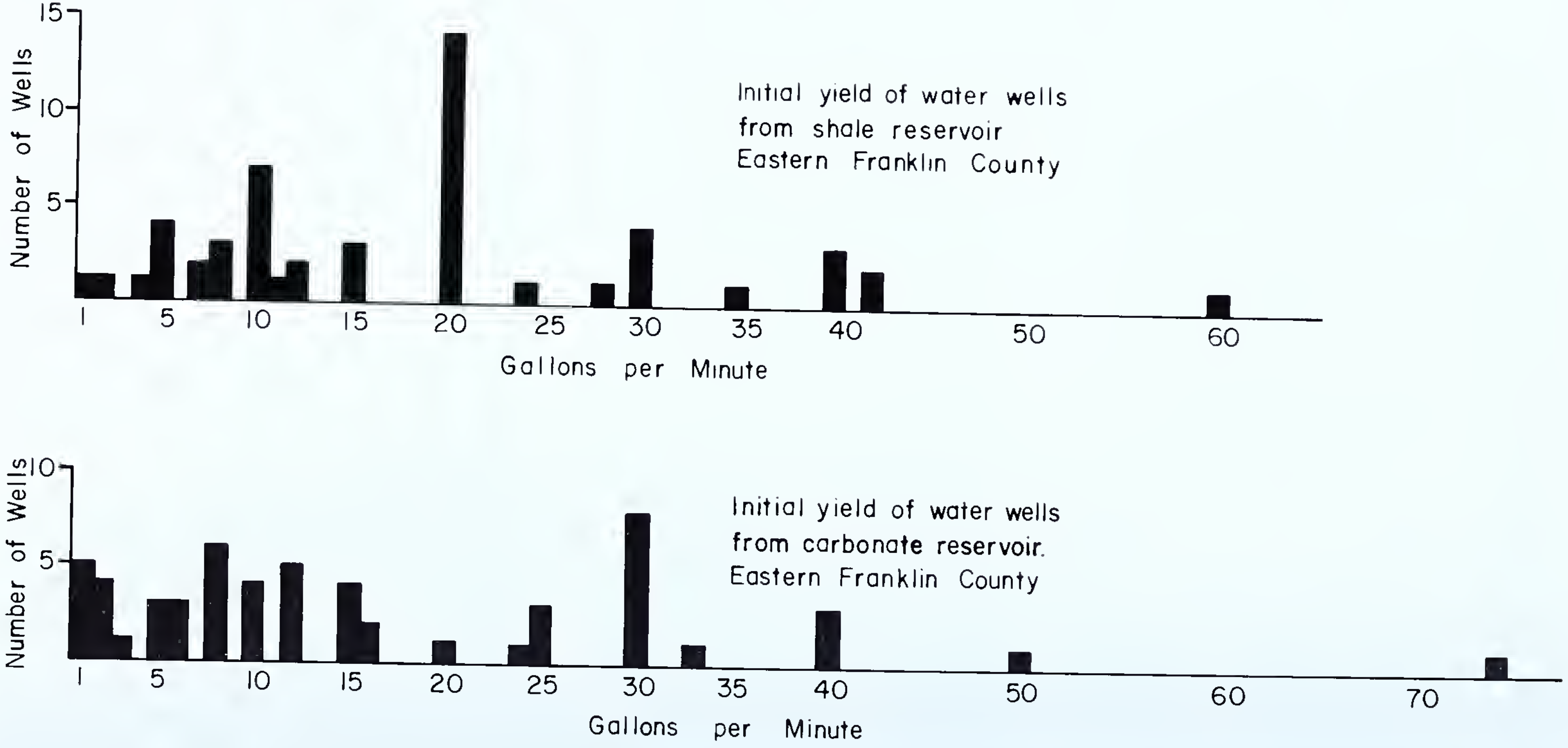

Figure 44. Yields of water in eastern Franklin County. Based principally on driller's estimates.

wells were drilled to depths of 350 feet without encountering water. As a whole there were fewer dry holes drilled in the shales than in the adjacent carbonates. The values of initial water yield must be used with caution as in most instances they represent a driller's estimate, and also they do not represent sustained tested yields.

A few wells were drilled in stream gravels or gravel colluvium at the base of South Mountain. Wells drilled east of Fayetteville ranged in depth from 45 feet to 375 feet and initial water yield ranged from 40 g.p.m. to 200 g.p.m. The best wells are apparently in the stream gravels.

A major source of water is the springs associated with faults. For instance Falling Spring, Aqua, and Rocky Springs are all associated with major faults (Plate 1). Some of the yields are large; e.g. in 1944 two separate tests at Falling Springs during the summer showed water at 50°F flowing at 900 g.p.m. and 1900 g.p.m.

This demonstrates that in drilling in carbonates the most productive wells are usually close to zones of faulting and often tight folding. Also the more pure, and consequently more soluble, limestones of the St. Paul Group, and pure marbleoid limestone at the base of the Rockdale Run and within the Zullinger Formations will be more productive aquifers than the adjacent less pure limestones. The dolomites of the Pinesburg Station Formation should also be a better than average aquifer as the dolomites are more fractured than the adjacent limestones. In addition, areas of the Martinsburg (Figure 25) that contain greywacke beds should be better aquifers than those areas composed wholly of shales which are less permeable.

ENVIRONMENTAL GEOLOGY

INTRODUCTION

The geology of a region constitutes the physical aspect of man's environment. The evaluation, utilization, and modification of the geologic features which interact with man and his works are termed environmental geology. Our knowledge of the physical environment is greatly enhanced through application of geologic concepts and techniques to develop our urban, agricultural, and industrial centers in such a way that we obtain the maximum benefits from, and with least harmful alteration to, our physical environment.

This section may therefore be utilized by urban and rural planners, construction engineers, and conservationists. Professional geological consultants should be used to translate these data to relevance for specific site projects.

Although the rocks are discussed under separate subjects that are of interest in environmental geology it should be noted that in many instances there is a distinct relation among the rock properties or that one property is dependent upon some other property.

Two factors tend to simplify the environmental geology of this region. Firstly although there are many different formations recognized in the carbonates, they generally have the same physical properties relative to environmental geology aspects. Consequently only two major rock types, carbonate and shale, need to be considered. Secondly since the terrain is principally of low, rolling relief the effects of topography upon these rocks can be neglected.

Description and thickness of the units are summarized in Figure 2. The distribution of the units is shown on the geologic map (Plate 1). Distribution of the different lithologies within the Martinsburg Formation is shown in Figure 25. The economic geology and hydrologic properties of the rocks are discussed in detail in the chapter on mineral resources.

Bedding

Bedding is the surface that divides sedimentary rocks of the same or different lithologies into layers. Bedding represents primary surfaces developed during the deposition of the sediment, and they are important in that they represent planes along which the solid rock will most easily part. This is useful for example in development of quarries (Figure 45) where bedding surfaces can be developed as structurally sound faces in quarry walls. Frequently caves develop along bedding surfaces or in the beds themselves (Figure 46).

The carbonates are moderately well bedded occurring in thick to massive beds especially in the dolomites. They are generally steeply dipping and moderately folded.

Rocks of the Martinsburg Formation (Figure 25) have a somewhat different character. The sandstones are well bedded in thick to massive beds that are generally steeply dipping and moderately folded. The shales and interbedded sandstones are moderately bedded and in thick to flaggy beds that are generally steeply dipping and strongly folded. The shales are poorly bedded and in laminae that are steeply dipping and very strongly folded. Actually, in weathered outcrop bedding is obliterated by cleavage and joint surfaces are preserved.

Fracturing

Fractures are breaks in rocks due to folding or faulting and include both joints and faults, however the latter is not considered in this section. These features are important in that they represent additional planes along which the rock will preferentially break, an important factor is ascertaining the strength of a rock in construction. Fractures are discussed in detail in the section on structural geology.

Joints are developed in the limestones in a regular array (Figure 47). However, the joints are only locally well developed and the spacing between them

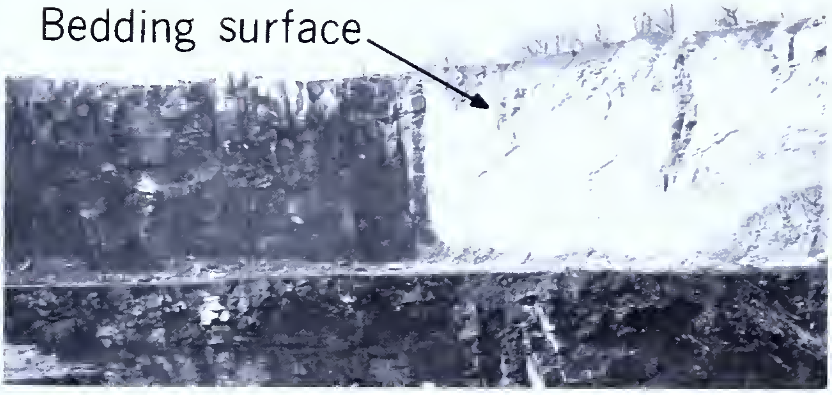

Figure 45. Vertical beds of the Stonehenge Formation in the Valley Quarries, Inc. crushed limestone quarry at New Franklin. These beds form a natural parting along which rock can readily be removed. Both the face developed along the bed and the face developed across the beds are vertical-indicating the high slope angle stability of the carbonates.

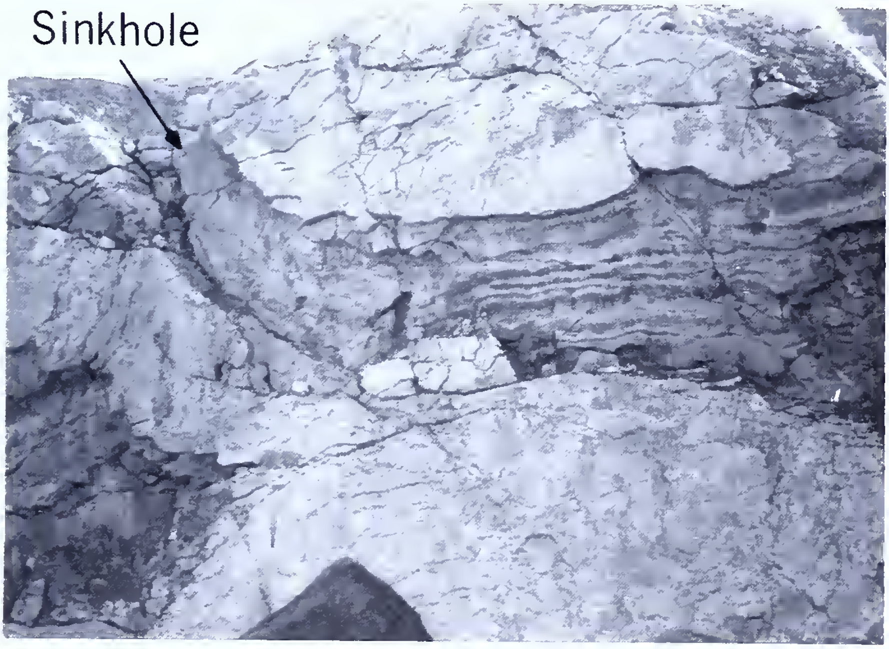

Figure 46. Cross-section of a sinkhole in limestone of the Stonehenge Formation. Note how the sinkhole development is confined within the vertical bed. Arrow points to sinkhole entrance.

is on the order of feet. They are generally filled with calcite or closed, although they may be secondarily enlarged by movement of ground water. The joints are generally perpendicular to bedding with one system dipping moderately and one set subhorizontal.

Joints are more abundant in the dolomites (Figure 19) but are of limited extent so that they may effectively be considered as a widely spaced system. The most important set is vertical and perpendicular to bedding.

Joints are important in the Martinsburg Formation as they are the principal parting plane in the shaly unit (Figure 48). They are regional and form a subvertical set that strikes N60°W-S60°E and are perpendicular to bedding. Spacing is on the order of inches where the outcrop is moderately weathered; where throughly weathered the joint set may be obscured. The distribution and spacing are regular. The joints are open at surface, decreasing in width opening downward. In the interbedded shales and sandstones jointing of the regional type described is of equal magnitude but in addition a secondary local joint set is also developed (Figure 49). In the sandstones the regional joint set is less well developed and the distribution and spacing is wider. However, a closely spaced regular joint system related to local folding is developed. This system is perpendicular to bedding, forming an intersecting moderately dipping system. A less well developed

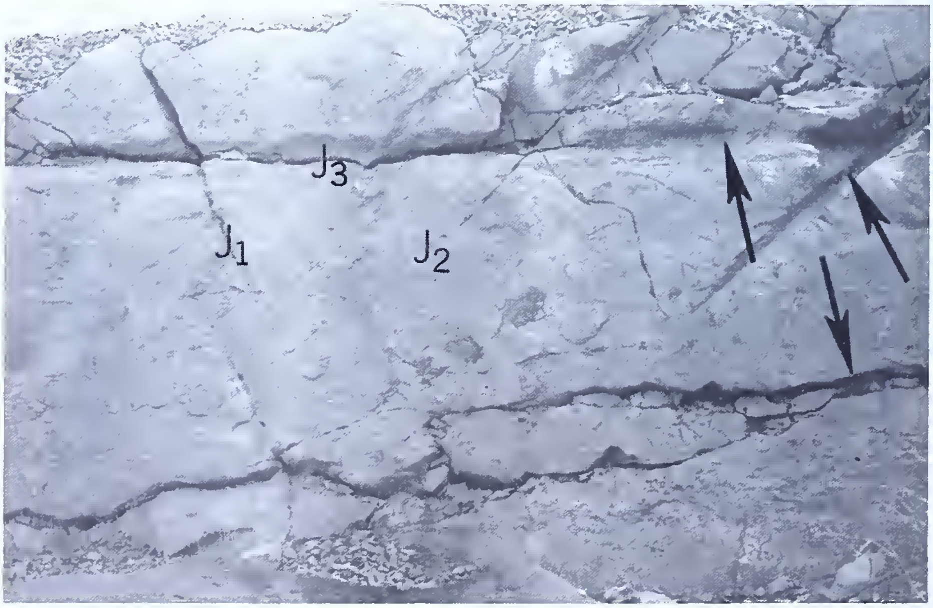

Figure 47. Development of joints in limestone. Joints are perpendicular to bedding with one intersecting system ($J_1 \times J_2$) at high angles to the ground surface and a single set (J_3) horizontal to the ground surface. The arrows point to joints which have been enlarged by movement of ground water.

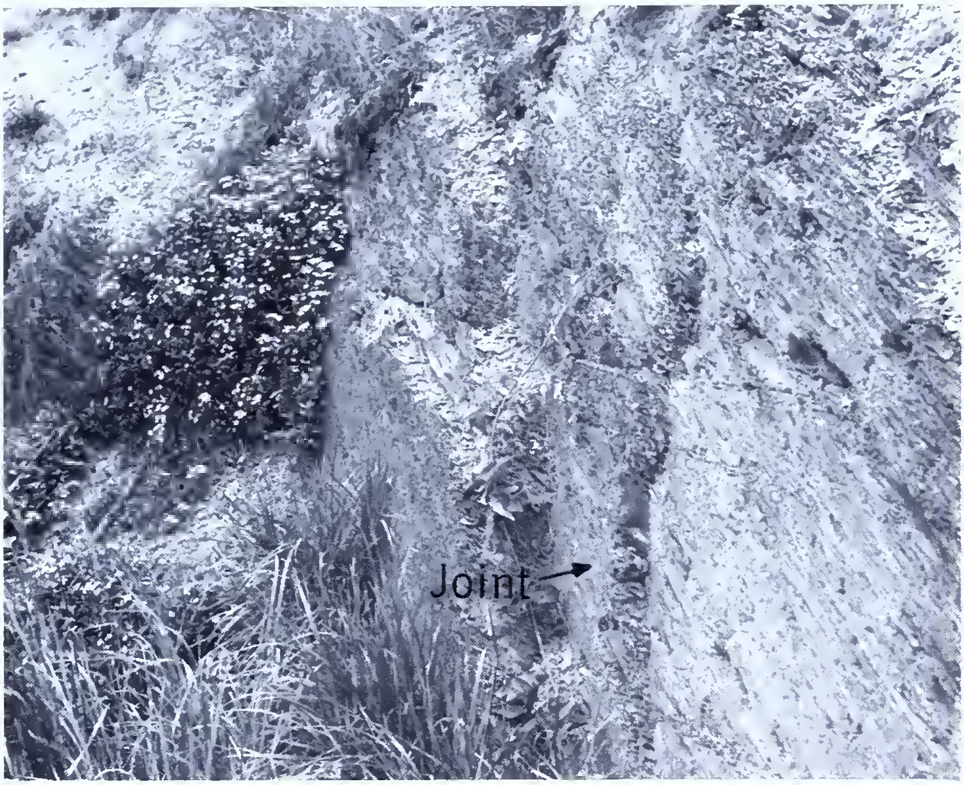

Figure 48. Set of vertical joint faces in the shaly lithofacies of the Martinsburg Formation. Joint spacing is several inches. Bedding cannot be determined because of weathering of the shale.

subhorizontal set perpendicular to bedding is also present. The local joint system is closely spaced (Figure 27) and as a result the sandstone weathers and breaks out as blocks.

Infiltration Capacity

Infiltration capacity is the maximum rate at which a particular unit, when in a given condition, can absorb falling rain. This infiltration capacity affects the groundwater recharge capacity of a formation and also its utility for septic system sewage disposal.

The infiltration capacity of the carbonates is high because their extremely soluble nature induces a secondary porosity to the rock. The limestones are highest in infiltration capacity and the dolomites somewhat less. This aspect of the rocks is apparent by their topographic expression (Plate 1) as few permanent streams flow in the carbonates and valleys are broad with subdued walls.

The infiltration capacity of the Martinsburg Formation is generally low because joints are the only natural rock openings. However, there are variations within the different lithologies because certain of the units have

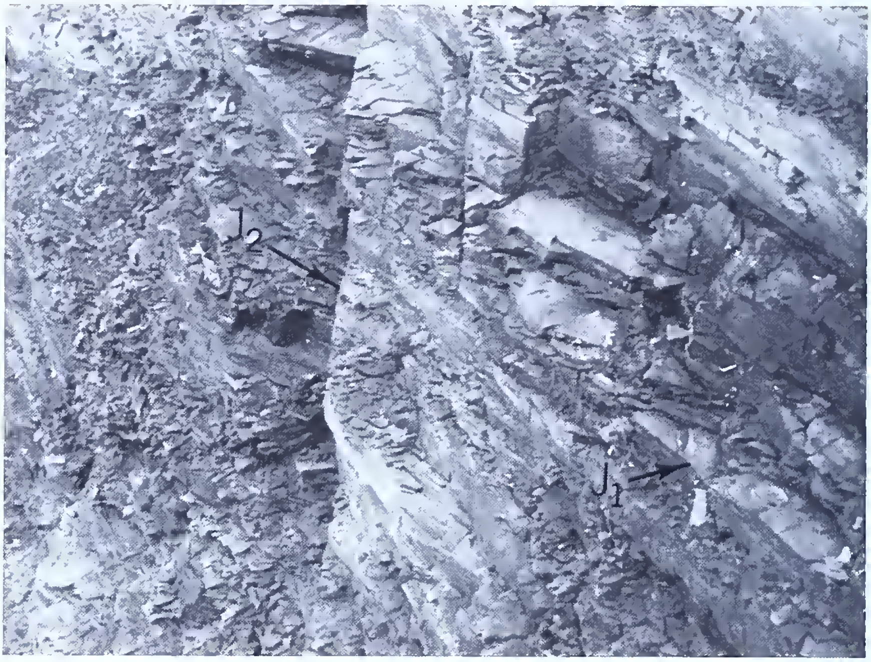

Figure 49. Intersecting system of vertical joints in nearly horizontal shales and interbedded sandstones of the Martinsburg Formation. J_1 is principal joint direction (N60°W) and J_2 is secondary joint direction (N10°W).

more fractures or fractures which are maintained open to greater depths. The infiltration capacity of the sandstone unit is highest, the shale and interbedded sandstone unit less high, and the shale unit is lowest. This aspect of the rocks is apparent by the topographic expression of the Martinsburg Formation as many permanent streams flow in narrow, steep walled valleys.

Alluvium, which occurs along the major streams in the area, has a high infiltration capacity. It is highest where composed of well sorted sands and gravels and somewhat lower where clay material occurs between grains.

Aquifer Potential

The aquifer potential, or water yield, of any given unit is related to its infiltration capacity and its structural position. The aquifer potential is discussed in detail in the chapter on mineral resources. Although these data here indicate that the apparent potential does not appear to differ significantly between the carbonates and the shales it should be noted that the carbonates locally may have prolific yields. This is due to such things as local cavernous conditions or enlargement of joints or bedding planes by solution (Figures 46 and 47) or shattering of the rocks by faulting. On the other hand the shales tend to have yields within a more restricted range as they are not soluble and do not shatter.

Carbonate reservoirs are generally in better communication with each other whereas shale reservoirs are more discrete. As a consequence, pollution or rapid depletion will affect an area more rapidly in the carbonates than the shales.

Weathering Character

Weathering, whereby rocks on exposure to weather change in character, decay and finally form soil, depends upon the physical characteristics of the unit and its reaction to climate, topography, and vegetation.

Carbonates weather mainly by chemical alteration and to a much lesser degree by physical disintegration. As a consequence the depth to bedrock surface varies considerably in these rocks and predictability as to bedrock depth and configuration of the bedrock surface is difficult. The carbonates are frequently exposed or just a few feet below surface on hilltops and several feet below surface in valley bottoms. Where bedrock surfaces have been excavated they are hummocky with small solution pinnacles and depressions (Figure 50). As the dolomites are less soluble than the limestone they form ridges that are several feet higher than the adjacent limestones. The bedrock surface is controlled by bedding and fractures. There is a sharp interface between solid bedrock and soil in these rocks.

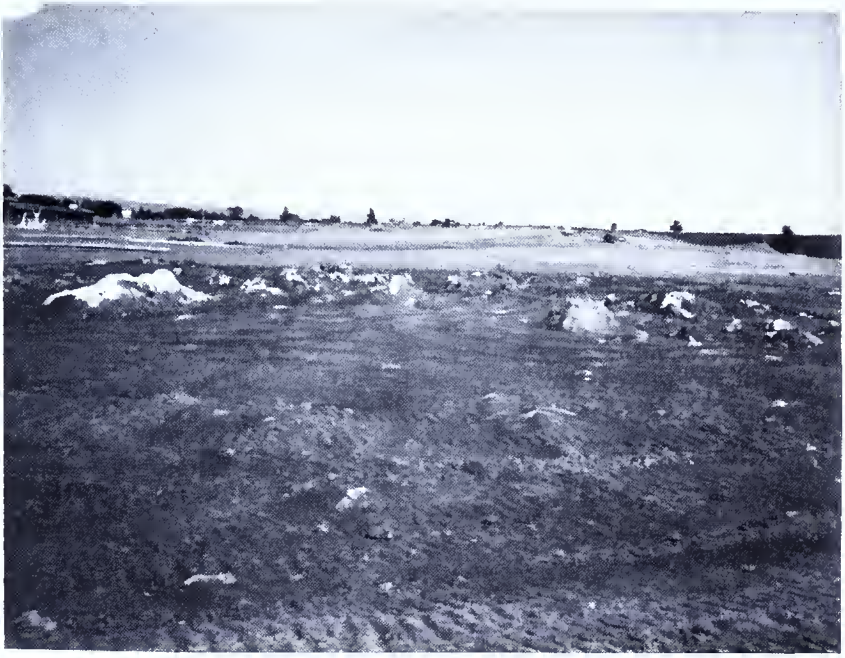

Figure 50. Excavated surface on limestone terrain. Note isolated pinnacle ridges that rise several feet above the general level of the limestone surface.

The Martinsburg Formation weathers mainly by physical disintegration. As a result depth to bedrock and configuration of the bedrock surface are fairly uniform. However, there is a zone a few feet thick composed of partially disintegrated shale between the soil and the solid bedrock. The Martinsburg does not crop out naturally because it weathers so rapidly. Depth to bedrock on hilltops is only a couple to several feet but increases to 20 feet or more in valley bottoms. The sandstones of the Martinsburg (Figure 25) are more resistant than the shales and are consequently closer to the surface than the shales.

Excavation Factors

Excavation of bedrock material requires considerably different techniques depending upon the rock type.

The carbonates are difficult to excavate and require heavy power equipment and blasting. The removal of overburden to get at the bedrock can be a problem because of the extremely irregular bedrock surface that frequently develops. The carbonates also break into huge blocks that are too large for removal without secondary breaking (Figure 51). This is especially true of the dolomites which are most difficult to excavate. Rotary drilling in the carbonates is moderately fast but the local occurrence of chert can cause excessive bit wear.

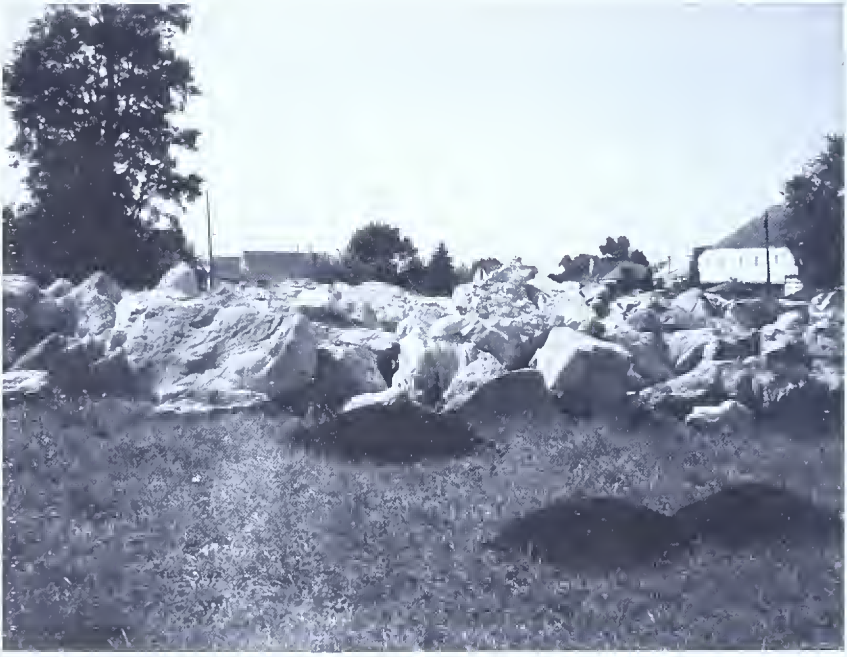

Figure 51. Huge blocks of Pinesburg Station dolomite resulting from blasting for foundation excavation. The blocks have been bulldozed off the foundation-site but are too large to be trucked away without secondary reduction of the blocks.

Rocks of the Martinsburg Formation are generally easy to excavate, especially the shale unit and shale and interbedded sandstone unit which can be excavated and removed directly by light power equipment. The sandstone unit may require heavy power equipment and locally may break into large blocks that require crushing prior to removal. Rotary drilling in the Martinsburg is generally fast although locally it may be only moderately fast in the sandstones.

Slope Stability

Only artificial slopes in cuts are considered in the mapped area. Natural slopes are so slight and appear to be stable so that normal modifications by man pose no problem.

The carbonates will maintain very high angles of slope to considerable depths with long term stability (Figure 45).

The sandstone unit of the Martinsburg Formation will maintain high angles of slope to moderate depth with short to medium term stability. Because of the abundance of open, relatively close spaced fractures the walls will begin to break into sandstone blocks especially in cuts that parallel bedding. Therefore, for long term stability only moderate slopes should be cut.

Other lithologies in the Martinsburg will maintain moderate angles of slope to moderate depths with long term stability. Cuts that parallel the regional joint set of N60°W-S60°E will quickly give problems on high slope angles.

Foundation Stability

The presence of carbonates immediately poses problems in ascertaining foundation stability. Although it has excellent quality of foundation and great stability for heavy structures the soluble nature of limestone and dolomite can create difficulties. Sinkholes and caverns in the rock may weaken the foundation so that it cannot support heavy structures. Therefore for heavy structures, highways, dams, and airfields the area must be tested to see if it is free of sinkholes and caverns. If present, in many instances these foundation flaws can be rectified by grouting, piles, etc. but in some instance these flaws cannot be rectified and the land cannot be used for that purpose. These preliminary remarks are presented as words of caution only, not condemnation, as generally the carbonates in Franklin County serve as excellent foundations. Care should be taken in heavy construction that water drains quickly away from the structure or else solution and foundation weakening may occur.

The rocks of the Martinsburg Formation, although basically not as good a foundation rock as the carbonates, do not have the problems associated with the carbonates. With proper footings or pilings heavy structures can be supported with high stability. Care should be taken that excavation is into solid bedrock and not a weathered zone.

Alluvium generally forms a poor foundation and is only suitable for light structures.

Construction Material

The use of the various rocks as a source of construction material is discussed in the chapter on mineral resources. Not considered in that chapter is that shales of the Martinsburg are used for base material on private driveways and local roads and seem well suited for this purpose.

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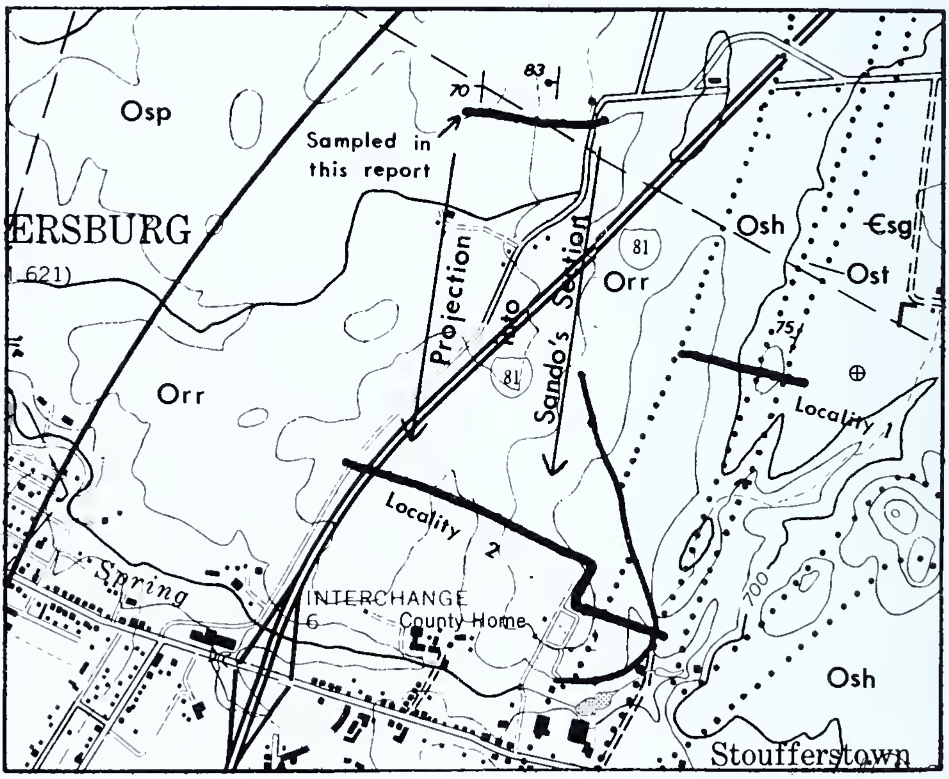
APPENDIX

MEASURED SECTIONS

Locality 1. This section was measured by Sando (1958) and is reproduced here by courtesy of the Geological Society of America and W. J. Sando. Some slight modifications are made to conform with stratigraphic usage of the Pennsylvania Geological Survey.

Stonehenge and Stoufferstown Formations

Section begins in wooded area near northwest corner of Hoover farm 2.2 miles east of the center of Chambersburg and extends westward into pastures of Franklin County Home. It follows line of section B on the sketch map.



Locality 1 and 2

Conochocheague Group

Thin bedded, fine-grained, mechanical detrital limestone without silty partings interbedded with laminated dolomitic limestone; no fossils seen; about 100 feet poorly exposed to axis of anticline.

Beekmantown Group

Stoufferstown Formation

Unit		Thickness (feet)
1	Limestone, mechanical, coarse-grained lithofacies; top and bottom poorly exposed; about 50 percent covered.	224.7
	Stonehenge Formation	
2	Limestone, algal?, massive; small gastropods.	93.0
3	Limestone, mechanical, fine-grained lithofacies.	35.0
4	Covered.	99.6
5	Limestone, algal?, massive, about 50 percent covered.	29.0
6	Limestone, mechanical, fine-grained lithofacies; gastropods; about 50 percent covered.	25.0
7	Limestone, algal?, massive; gastropods and cephalopods.	17.0
8	Limestone, mechanical, fine-grained lithofacies.	4.0
9	Limestone, algal, channeled; gastropods.	23.0
10	Limestone, mechanical, fine-grained lithofacies; gastropods and cephalopods.	5.0
11	Limestone, algal?, massive; gastropods and cephalopods.	16.0
12	Limestone, mechanical, fine-grained lithofacies; brachiopods and gastropods.	19.0
13	Covered.	32.9
14	Limestone, mechanical, fine-grained lithofacies; brachiopods, gastropods, and pelmatozoan remains; about 50 percent covered.	46.0
15	Covered.	56.2
16	Limestone, mechanical, fine-grained lithofacies; brachiopods, gastropods, and pelmatozoan remains; lower half about 50 percent covered.	44.0

Rockdale Run Formation

Note: In this report the base of Rockdale Run Formation is selected at the base of Sando's Unit 17. Sando included units 17 and 18 at the top of the Stonehenge Formation.

17	Dolomitic limestone, laminated.	3.0
18	Limestone, mechanical, interbedded coarse-grained (about 60 percent) and fine-grained lithofacies; some oolitic beds containing asaphid trilobite fragments and gastropods; about 50 percent covered.	144.0
	Total	691.7

Locality 2. This section was measured by Sando (1958) and is reproduced here by courtesy of the Geological Society of America and W. J. Sando. Some slight modifications are made to conform with stratigraphic usage of the Pennsylvania Geological Survey.

Stonehenge Formation in part and Rockdale Run Formation in part

Section begins on hill in pasture on Hoover farm west of house and extends westward across Franklin County Home to farm west of home. Traverse begins at base of hill about 150 feet west of small stone bridge on Falling Spring Branch. Northwest-striking gully, represents the trace of a fault. It follows line of section A on the sketch map.

Stonehenge Formation

Unit		*Thickness (feet)*
1	Limestone, mechanical, fine-grained lithofacies; *Lytospira*? sp. 9 feet below top, trilobites, gastropods, and pelmatozoan debris throughout.	71.0
2	Covered.	26.3
3	Limestone, mechanical, fine-grained lithofacies.	23.0
4	Limestone, mechanical, coarse-grained lithofacies; *Lytospira*? sp., trilobites, pelmatozoan debris.	11.0
5	Limestone, mechanical, coarse-grained lithofacies; *Finkelnburgia bridgei* at top.	20.0
6	Limestone, mechanical, coarse-grained lithofacies; trilobites and pelmatozoan debris.	53.0
7	Limestone, mechanical, fine-grained lithofacies; trilobites and pelmatozoan debris.	12.0
8	Limestone, mechanical, coarse-grained lithofacies; *Lytospira*? sp., trilobites, and pelmatozoan debris.	52.1
9	Limestone, mechanical, oolitic; *Lytospira* sp., *Bellefontia collieana*?, merostome fragments, and indeterminate conodonts.	2.0
10	Limestone, mechanical coarse-grained lithofacies; *Finkelnburgia* sp., inarticulate brachiopod fragments, and *Drepanodus* sp. *A* and *D* 15.1 feet above base.	24.4
11	Limestone, mechanical, fine-grained lithofacies; *Lytospira*? sp., trilobites, and gastropods.	16.5
12	Limestone, mechanical coarse-grained lithofacies.	4.0
13	Limestone, mechanical, fine-grained lithofacies; *Lytospira*? sp.	20.9
14	Limestone, mechanical, coarse-grained lithofacies.	7.7
15	Limestone, mechanical, fine-grained *Lytospira*? sp. and trilobites.	8.4
16	Limestone, mechanical, coarse-grained lithofacies; *Lytospira*? sp.	7.7
17	Covered, but with a few outcrops of mechanical limestone, more complete exposures 200 feet north of traverse line show an oolitic bed 49 feet above base bearing *Lytospira*? sp., trilobites, *Acontiodus* sp. *E*, *Acanthodus* sp. *A*, *Distacodus* sp. *A*, *Drepanodus* sp. *C* and *D*, *Oistodus* sp., and *Scoloposdu* sp.	96.1
18	Limestone, mechanical, interbedded fine-grained and coarse-grained lithofacies, dominantly the former; oolitic in part; *Tentaculites* sp., gastropods, and brachiopods.	37.1
	Measured thickness of Stonehenge Formation	493.2

Rockdale Run Formation

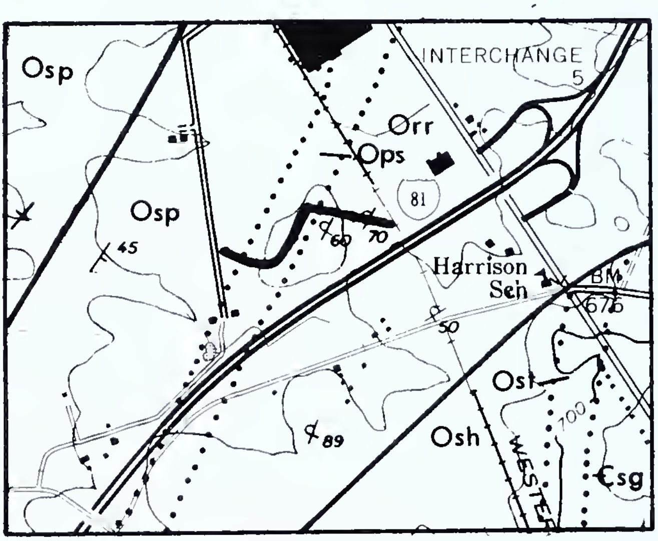
19	Dolomitic limestone, laminated.	1.0
20	Limestone, mechanical, fine-grained lithofacies; *Tentaculites loudoni* and an indeterminate conodont in upper 2 feet, pelmatozoan debris throughout.	21.6
21	Covered; a few outcrops of mottled limestone and mechanical limestone near top.	136.3
22	Limestone, mechanical, calcilutite and calcisilite, pure.	3.0
23	Limestone, algal; cryptozoon heads 7 inches in diameter and 3 inches high, consisting of broad gentle upwarping of laminae.	1.0
24	Limestone, mechanical, calcilutite and calcisiltite, pure; nodular black chert parallels bedding.	4.0
25	Dolomitic limestone; laminated.	2.0

Unit		*Thickness (feet)*
26	Limestone, mechanical, calcilutite and calsiltite pure; strongly sheared.	1.0
27	Covered.	131.0
28	Limestone, mechanical, dominantly fine-grained lithofacies; some dolomitic banding and mottling; *Lecanospira* sp. and *Acontiodus* sp. *A* 31.5 feet above base.	61.0
29	Limestone, mechanical, oolitic; ooliths 0.25–0.5 mm in diameter; *Lecanospira* sp. and *Macluritella* sp. (Good exposures of *Lecanospira* zone and beds immediately above and below it may be seen in abandoned quarry about 400 feet south of traverse line.)	6.5
30	Covered; a few outcrops of mechanical limestone.	15.0
31	Dolomite; laminated.	2.0
32	Limestone, algal, massive; gymonsolenid stromatolites; small gastropods; about 50 percent covered.	28.0
33	Covered, a few outcrops of mechanical limestone.	78.0
34	Limestone, mechanical, dominantly fine-grained lithofacies; endoceroid cephalopod siphuncles 5 feet above base *Leiostegium* cf. *L. puteatum*, macluritid gastropod, pelmatozoan fragments, and indeterminate conodonts 7 feet above base.	60.0
35	Limestone, interbedded algal (about 60 percent) and mechanical; stromatolites mainly gymnosolenid type but at least one zone of pycnostromids; gastropods; pelmatozoan debris, and cephalopods common throughout; *Escharendoceras simplex*, other endoceroid siphuncles, indeterminate brachiopod, and *Scolopodus quadraplicatus* 3 feet above base; *Archaeoscyphia annulate*? 36 feet above base.	90.0
36	Covered; a few outcrops of mechanical and algal limestones; outcrops just above base of unit south of traverse line yielded *Diparelasma*? sp., *Mcqueenoceras*? sp., and indeterminate endoceroid siphuncles, ophiletid gastropods, and an indeterminate conodont.	70.5
37	Limestone, interbedded algal (about 50 percent) and mechanical; gymnosolenid stromatolites; gastropods, pelmatozoa, and cephalopod siphuncles throughout.	23.5
38	Dolomitic limestone; mottled; appears to represent partial dolomitization of mechanical limestone.	1.5
39	Limestone, algal; gymnosolenid stromatolites.	9.0
40	Dolomite, laminated.	4.0
41	Limestone, interbedded algal (about 60 percent) and mechanical; gymnosolenid stromatolites.	31.0
42	Orthoquartzite; well-rounded quartz sand grains 1 mm or less in diameter in a calcareous and dolomitic matrix along with a few pebbles of dolomite.	8.5
43	Limestone, interbedded algal (about 60 percent) and mechanical; gymnosolenid stromatolites.	26.5
44	Dolomitic limestone; mottled, like unit 38.	1.5
45	Limestone, interbedded algal (about 60 percent) and mechanical; gymnosolenid stromatolites.	31.0
46	Covered and unreliable outcrops of limestone.	69.0
47	Covered.	102.0
48	Covered: a few outcrops of limestone; distance paced.	111.0
49	Covered; interval occupied by orchard and sewage disposal plant.	172.1

Unit		*Thickness (feet)*
50	Limestone, mechanical, dominantly fine-grained lithofacies; some dolomitic mottling and banding; *Diparelasma* cf. *D. marylandicum*, *Tritoechia* sp., *Isoteloides* cf. *I. flexus*, ophiletid gastropod, pleurotomarian gastropod, *Acodus* sp., *Drepandos* sp. A and C, and *Oistodus* sp. A and *B* 15 feet above base; gastropods and pelmatozoan debris abundant throughout.	76.0
51	Covered.	28.9
52	Limestone, mechanical (about 70 percent) and algal; gastropods, cephalopods, and pelmatozoan debris throughout; about 60 percent covered.	261.0
53	Covered; a few outcrops of limestone and dolomite give control to the traverse; blocky chert common in soil.	658.0
54	Covered.	32.5
55	Covered; distance scaled from aerial photo; section ends at point on axis of major syncline projected from position of outcrops to south.	188.0
	Measured thickness of Rockdale Run Formation	2546.9

Summary

Measured thickness of Rockdale Run Formation (incomplete, 74 percent covered)	2546.9
Measured thickness of Stonehenge Formation (incomplete, 25 percent covered)	493.7



Locality 3

Locality 3. This section contains a complete thickness of the Pinesburg Station Formation and parts of the overlying and underlying units. It was sampled and analyzed for acid insoluble residue. The results are presented in Plate 2.

The base of the section begins near the Western Maryland Railroad tracks where they pass under Interstate 81 near interchange 5. From here the section follows westward along the ledges of outcrop.

St. Paul Formation (238 feet—incomplete)

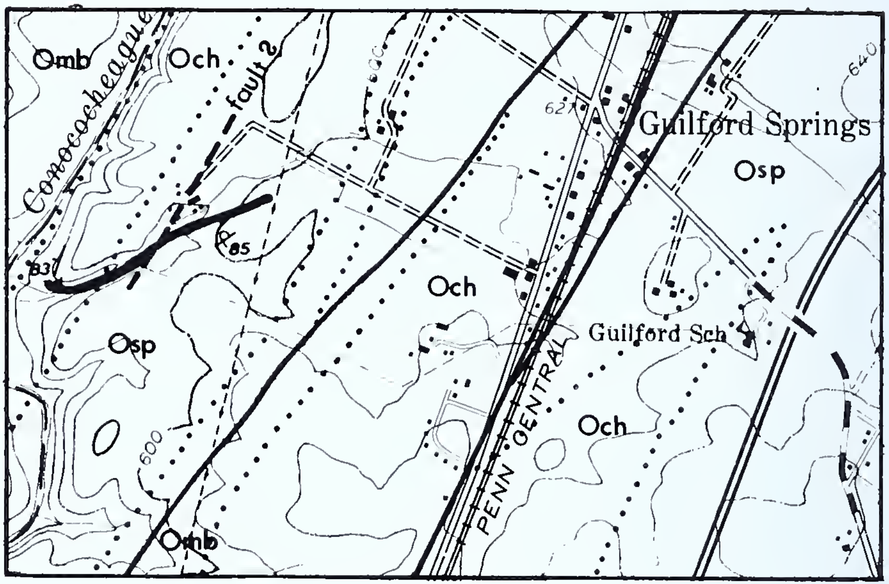
Unit		*Thickness (feet)*
128	(10 percent exposure) Limestone, gray with blue cast, micritic skeletal to detrital, abundant irregular bands of dolomite and dolomite mottlings; in beds 2 feet thick.	200.0
127	Interbedded limestone and dolomite. Dolomite medium-gray, weathers buff, in beds 2 to 3 feet thick. Limestone, medium-gray, weathers medium gray with blue cast, detrital to skeletal semimicritic, with abundant crinkled dolomite laminae. About 50 percent exposure in this interval; with dolomite: limestone beds, 2.1.	38.0
	Beekmantown Group	
	Pinesburg Station Formation (255 feet thick)	
126	Dolomitic shale, buff, finely laminated, fissile, weathers in $\frac{1}{16}$ inch plates.	7.7
125	Limestone, similar to Unit 97; 30 percent exposed.	20.0
124	Dolomite, similar to Unit 69, with some chert.	2.5
123	Limestone, similar to Unit 116.	11.0
122	Covered interval.	15.5
121	Dolomite, similar to Unit 69.	1.0
120	Limestone, similar to Unit 97.	5.2
119	Covered interval.	3.5
118	Limy dolomite, similar to Unit 69, but not as blocky.	1.7
117	Covered interval.	26.0
116	Limestone, gray with blue cast, banded, with some bands internally laminated.	3.5
115	Dolomite, similar to Unit 69, 50 percent exposed.	14.0
114	Dolomite, similar to Unit 69.	17.0
113	Covered interval.	15.5
112	Dolomite, similar to Unit 106.	2.5
111	Dolomite, similar to Unit 69. Some white and black chert.	14.5
110	Dolomite, black, medium crystalline to granular, with faint laminations. Some tiny quartz crystal present. Some black chert nodules to several inches.	1.7
109	Dolomite, similar to Unit 69. Some black chert at top and white chert throughout.	33.0
108	Dolomite, similar to Unit 69. Some 2-foot beds of dark-gray, coarsely-crystalline, slightly limy dolomite.	32.0
107	Limy dolomite, dark-gray, mottled and burrow structures, limy patches to irregular bands at top, more dolomite towards base.	17.0
106	Dolomite, alternating bands of light-gray and medium-gray weathering. The darker bands are laminated light and dark dolomite showing current structures. The lighter bands are structureless.	2.5
105	Dolomite, similar to Unit 69.	7.0

Unit		*Thickness (feet)*
	Rockdale Run Formation (700 feet, incomplete)	
104	Limestone, similar to Unit 97.	3.0
103	Dolomite, similar to Unit 69.	0.5
102	Limestone, similar to Unit 97.	2.5
101	Dolomite, similar to Unit 69.	3.5
100	Limestone, similar to Unit 77.	3.5
99	Limestone, similar to Unit 97.	4.5
98	Dolomite, similar to Unit 69.	5.2
97	Limestone, medium-gray, weathers medium gray with blue cast, semimicritic to micritic, in 2 to 4 inch bands separated by crinkled dolomitic laminae.	2.5
96	Dolomite, similar to Unit 94.	7.0
95	Limy dolomite.	1.0
94	Dolomite, similar to Unit 69, but with finer planar laminations.	4.5
93	Limestone, similar to Unit 85.	3.5
92	Dolomite, similar to Unit 69, but with isolated laminae and slight banding due to subtle color tone variation.	3.0
91	Limestone, similar to Unit 85.	1.7
90	Dolomite, similar to Unit 69.	4.5
89	Limestone, similar to Unit 77.	9.5
88	Dolomite, similar to Unit 69.	4.7
87	Limestone, similar to Unit 77.	4.8
86	Dolomite, similar to Unit 79.	3.0
85	Limestone, light medium gray with blue cast, weathers muddy-gray, semimicritic to micritic with very fine skeletal and detrital grains. Some thin bands of laminated dolomite and also crinkled laminae. Locally disseminated buff dolomite crystals.	2.6
84	Dolomite, similar to Unit 69.	1.0
83	Covered interval.	1.0
82	Limestone, similar to Unit 79.	1.0
81	Dolomite, similar to Unit 69.	4.5
80	Covered interval.	6.0
79	Limestone, similar to Unit 77, but fewer burrow structures and more irregular dolomites interbands.	6.0
78	Covered interval.	13.0
77	Burrowed to mottled limestone, medium gray with blue cast, very fine sparse skeletal and detrital semimicrite limestones. With anastomosing burrows along bedding filled with muddy dark gray dolomite with blue cast. Very abundant development of 1 to 3 inch white to pinkish-white chert rosettes.	7.0
76	Covered interval.	13.0
75	Dolomite, similar to Unit 69.	3.5
74	Limestone, similar to Unit 71.	8.5
73	Covered interval.	16.5
72	Dolomite, similar to Unit 69.	1.0
71	Limestone, medium gray with blue cast, weathers medium gray with dark cast, micritic with sparse very-fine detrital-skeletal-pellet material. With sparse crinkled dolomite laminae.	3.5
70	Covered interval.	16.5

Unit		Thickness (feet)
69	Dolomite, medium gray with blue cast, weathers medium gray, very fine crystalline, structureless to locally with planar laminations, blocky fracture.	9.5
68	Limestone, medium gray, weathers light gray with dark cast, skeletal micritic to skeletal-pellet micritic, with some well preserved bryozoa to ½ inch. Sparse crinkled dolomitic partings.	1.7
67	Covered interval.	14.5
66	(30 percent exposed) Dolomite, similar to Unit 52.	5.2
65	Covered interval.	8.0
64	Dolomite, similar to Unit 52.	2.0
63	Limestone, similar to Unit 31.	4.0
62	Covered interval.	3.0
61	Dolomite, similar to Unit 23.	3.0
60	Dolomite, similar to Unit 52.	2.0
59	Covered interval.	20.0
58	Limestone, similar to Unit 31.	3.0
57	Interbanded limestone and dolomitic limestone, gray and medium dark gray bands with blue cast that all weather with medium gray dolomite-like surface. Some internal laminations within ¼ to 2 inch thick bands. Locally isolated brachiopod values.	9.0
56	Limestone, similar to Unit 31.	3.0
55	Covered interval.	8.0
54	Dolomite, similar to Unit 52. Current features show that beds are overturned to southeast.	4.0
53	Limestone, similar to Unit 31. Some patches are coarsely crystalline.	12.0
52	Dolomite, medium to light gray with blue cast, weathers light gray; very finely laminated principally with planar and parallel laminations.	4.0
51	Covered interval.	10.0
50	Interbanded limy dolomite and dolomitic limestone in bands ½ to 1½ inches thick. Dolomite is medium gray with dark cast and internally laminated. Limestone is medium gray with blue cast, and very fine grained micritic detrital with abundant individual medium dolomite crystals throughout. At base dolomite in beds 4 inches thick.	6.0
49	Limestone, similar to Unit 31.	20.0
48	Covered interval.	6.0
47	Burrowed limestone, medium gray to dark gray with blue cast, weathers light gray, with pervasive burrowed structures of dark gray dolomitic limestone. Nearly all micritic skeletal limestone. Some complete small brachiopod valves especially in burrows. Abundant chert throughout.	17.0
46	Covered interval.	16.0
45	Limestone, similar to Unit 10.	1.0
44	Covered interval.	6.0
43	Limestone, similar to Unit 10.	2.0
42	Dolomite, medium gray with blue cast, weathers light muddy-gray, finely crystalline, fine laminations locally shows current effects. Trace of limestone clasts as microconglomerate. Some chert present.	3.0
41	Limestone, interbedded similar to Unit 31. Generally in 4-foot beds. Subordinate 2-foot beds of semimicritic limestone with minor semi-planar dolomite bands and mottling.	38.0

Unit		*Thickness (feet)*
40	Dolomite, very light gray with blue cast, weathers muddy gray, medium crystalline, structureless, slightly limy in a few places.	4.0
39	(60 percent exposed) Limestone, similar to Unit 31.	19.5
38	Dolomite, medium to medium-dark gray, banded, some bands are internally laminated.	2.0
37	Limestone, similar to Unit 10 but more dolomitic burrows.	14.0
36	Interbanded limestone and dolomite, similar to Unit 19.	1.0
35	Dolomite, medium-gray, fine to very-finely crystalline, laminated; with bands of microconglomerate composed of limestone clasts and shells in dolomite matrix.	0.5
34	Limestone, similar to Unit 10.	9.0
33	Limestone, similar to Unit 31.	6.0
32	Covered interval.	11.0
31	Limestone, dark gray with blue cast, very fine pellet to skeletal limestone with spar between grains; locally semimicritic with irregular buff dolomitic laminae to bands at ½ to 1 inch intervals forming an anastomosing pattern.	2.0
30	Covered interval.	7.0
29	Interbanded limestone and dolomite. Dolomite is muddy gray, laminated and finely crystalline. Limestone is dark gray with blue cast. Banding irregular to boudinage of the limestone. Some cream chert nodules.	1.5
28	Limestone, gray with blue cast, semi-micritic, with abundant buff gray dolomite filled burrows.	0.5
27	Covered interval.	5.0
26	Dolomite, buff gray, planar laminated.	0.5
25	Interlaminated limestone and dolomite, shows microconglomerate in part.	0.5
24	Mottled to burrowed limestone, medium gray with blue cast, semimicritic to slightly skeletal; with irregular burrows filled by buff dolomite matrix containing fine detrital limestone grains. Creamy chert rosettes present.	3.0
23	Mottled to banded dolomite, medium dark-gray, weathers medium gray with dark cast, finely to very-finely crystalline, abundant internal laminations showing current features; with irregular mottlings and burrows of lighter colored limy dolomite and boudins to irregular bands of gray with blue cast laminated limestone—locally becomes interbanded.	7.0
22	Limestone, similar to Unit 10.	3.0
21	Dolomite, light gray with blue cast, weathers medium gray, very finely crystalline, structureless, blocky fracture.	6.0
20	Limestone, similar to Unit 10.	9.0
19	Interbanded limestone and dolomite, in equal proportions. Dolomite in 1 inch bands and internally laminated. Limestones in 1 inch bands, micritic to semimicritic, structureless.	1.0
18	Covered interval.	2.5
17	Limestone, similar to Unit 10.	5.5
16	Covered interval.	29.0
15	Dolomite, medium buff-gray, very finely crystalline, with laminations showing current features, in bands 4 inches thick. Some irregular ½ to 1 inch bands to boudins of micritic limestone.	2.0

Unit		*Thickness (feet)*
14	Burrowed limestone, medium gray with blue cast, semimicritic, with locally 60 percent of rock dolomite as buff medium gray filling of burrow system along bedding. Local development of white to creamy rosette chert to ¾ inch.	8.0
13	Limestone, similar to Unit 10.	5.0
12	Limestone, medium gray with blue cast, semimicritic to locally micritic; with 2-foot beds intensively burrowed and filled by dolomite. Some 2-foot interbeds with semiplanar to irregular dolomite bands. Some well preserved gastropods.	26.0
11	Dolomite, similar to Unit 3.	0.5
10	Limestone, dove colored, micritic, with sparse small ($\frac{1}{16}$ to $\frac{1}{4}$ inch) burrows that contain vague concentrations of fine buff dolomite crystals. Also vague laminae defined by sparse isolated dolomite crystals.	11.5
9	Limestone, similar to Unit 4.	2.0
8	Dolomite, medium dark-gray, weathers with buff cast, very finely crystalline, finely laminated but irregular to stylolitic.	0.5
7	Covered interval.	38.5
6	Similar to Unit 1.	3.0
5	Covered interval.	24.0
4	Limestone, gray with dark cast, semimicritic, in beds to 4 inches thick; with abundant burrowing along bedding, filled by very finely crystalline medium buff-gray dolomite.	6.3
3	Dolomite, medium gray, weathers medium yellow-gray, composed of thin bands that are internally laminated and locally show mud cracks; separated by ⅛ to 2 inch bands of very fine intraformational conglomerate (clasts to ¼ inch) of dolomite chips and limestone pellets and detrital grains in either limestone or dolomite matrix respectively.	0.7
2	Covered interval.	2.5
1	Limestone, light gray with blue cast, micritic-almost a vaughanite; with small patches skeletal fragments composed of clear spar. In 2 to 4 inch bands separated by semiplanar but crinkled dolomitic lamina. With some irregular burrowings filled by medium yellow dolomite.	4.5



Locality 4

Locality 4. This section includes the upper part of the St. Paul Group and the lower part of the Chambersburg Formation. There is a probable fault in Unit 66 of the St. Paul Group repeating part of the St. Paul Group. Analyses of acid insoluble residues from this section are presented in Figure 42.

The base of the section is about 3,000 feet west of Guilford Springs, and from there follows westward along ledges on the northwest side of the stream that flows into Conococheague Creek.

Chambersburg Formation (383 feet—incomplete)

Unit		*Thickness (feet)*
99	Limestone, medium dark gray, weathers a medium light gray with a dark cast, semimicritic with abundant fine to medium clastic grains some of which are biogenic; irregular buff argillaceous dolomitic laminae interconnect with abundant dark gray "worm tubes" to impart a fine cobbly habit to the rock.	5.0
98	Covered interval.	76.0
97	Limestone, medium light gray, weathers a medium light gray with a dark cast, semimicritic but locally with fine detrital grains as laminae or dispersed; in well defined beds 2 to 5 inches thick separated by ¼ to ¾ inch bands of buff argillaceous dolomitic limestone that weathers as a depression; bands are gently undulose imparting a coarse cobbly habit to the rock.	54.5
96	Limestone, medium dark gray, weathers medium gray, semimicritic with abundant fine to coarse clastic grains in layers and patches, locally with abundant fossils; in irregular 1 to 2 inch thick cobbly beds separated by buff argillaceous dolomitic limestone layers; 50 percent exposed.	40.0

Unit		*Thickness (feet)*
95	Limestone, similar to Unit 97.	14.5
94	Limestone, similar to Unit 99, but fewer "worm-tubes" intersect the dolomitic laminae and the rock therefore forms coarser cobbles.	17.5
93	Limestone, similar to Unit 97.	14.0
92	Covered interval.	8.0
91	Limestone, similar to Unit 99.	5.0
90	Limestone, similar to Unit 97.	24.0
89	Limestone, similar to Unit 99 but with coarser cobbly habit.	18.0
88	Limestone, similar to Unit 97, 70 percent exposed.	32.0
87	Limestone, similar to Unit 97, with *Nidulites* and crinoids.	24.5
86	Limestone, similar to Unit 99, with good specimens of *Nidulites*, crinoid columnals, orthocone cephalopods, and fucoid marking.	3.0
85	Covered interval.	13.0
84	Limestone, similar to Unit 97.	34.0
St. Paul Group (790 feet—incomplete)		
83	Covered interval.	40.4
82	Limestone and dolomite, interlaminated to interbanded; 60 percent very fine to coarse grained clastic limestone with rare dolomite clasts, in bands to 4 inches thick; 40 percent light buff dolomite in hair-thick laminations to ⅛ inch thick bands.	2.1
81	Stromatolitic limestone complex, light medium gray to dove colored, weathers light gray micritic and birdseye limestone in places; locally with channels and interbeds of fossiliferous material including *Tetradium* and some networks clear calcite spar filling; in a few places shows complex stromatolitic forms; in beds 1 to 2 feet thick.	50.0
80	Limestone, medium dark gray, weathers muddy medium gray, semimicritic with irregular lenses and dispersed fine to medium clastic limestone grains; with medium gray dolomite as irregular patches and "burrows" or very irregular bands that impart "worm-eaten" appearance to rock.	34.5
79	Stromatolitic limestone, micritic, with colonies *Tetradium* in places and locally other fossils.	14.5
78	Similar to Unit 82.	1.3
77	Limestone, medium dark gray, weathers medium light gray, semimicritic to locally medium-grained clastic limestone; with wispy dolomite bands to laminations, in 2 to 8 inch beds.	5.5
76	Similar to Unit 82.	3.0
75	Stromatolitic limestone, micrite (vaughanite) to birdseye near top, massive.	5.3
74	Limestone, medium gray, weathers medium dark gray, coarsely clastic with abundant fossils; patches of micritic limestone and dolomite; in irregular bands, 2 to 4 inches thick.	2.5
73	Covered interval.	7.0
72	Similar to Unit 80.	6.0
71	Similar to Unit 82.	1.8
70	Similar to Unit 77.	5.0
69	Similar to Unit 82, pinches out in 10 feet along strike. Most of the dolomites at about this stratigraphic level are local and described principally to show magnitude of dolomite in the section.	7.0

Unit		Thickness (feet)
68	Similar to Unit 77.	6.5
67	Similar to Unit 82.	1.8
66	Stromatolitic limestone, micrite (vaughanite).	3.7
65	Similar to Unit 82.	1.0
64	Limestone, medium dark gray, weathers medium gray with a blue cast, finely clastic to semimicritic matrix with abundant shells of brachiopods and snails to ¾ inch across; with light gray wispy crinkly dolomite laminae; in 1-foot beds.	5.1
63	Similar to Unit 82, but shows current structures.	1.5
62	Limestone, medium dark gray, weathers medium blue gray, very coarsely clastic with abundant fossils; irregular dolomitic bands spaced 1 to 2 inches and dolomitic patches yield a rock with "worm-eaten" appearance.	4.3
61	Similar to Unit 82.	1.2
60	Limestone, medium dark gray, weathers medium light gray, micritic to in places medium grained clastic lenses; locally with ¼ inch thick muddy gray dolomitic bands to wispy laminations; in beds 4 to 6 inches thick.	13.0
59	Similar to Unit 82.	2.3
58	Stromatolitic limestone, micritic (vaughanitic).	4.7
57	Covered interval.	1.8
56	Dolomite, limy, buff, with limestone laminations.	0.3
55	Similar to Unit 58.	2.5
54	Limestone, medium gray to buff with a blue cast, medium to coarse grained clastic texture with fossil detritus; matrix dolomitic, in part yielding a blotchy color to the rock.	1.7
53	Covered interval.	3.2
52	Similar to Unit 54.	0.8
51	Limestone, medium gray, semimicritic to locally finely clastic; in bands 1 to 2 inches thick separated by undulose irregular medium dark gray dolomitic lamina ⅛ to ¼ inch thick.	5.9
50	Similar to Unit 54.	0.7
49	Limestone, medium dark gray, weathers light medium gray with a blue cast, finely clastic to semimicritic matrix, contains abundant brachiopod and snail shells to ¾ inches in size; with wispy crinkly dolomite laminae; in beds 1-foot thick.	3.3
48	Covered interval.	2.2
47	Similar to Unit 54.	0.7
46	Similar to Unit 62.	4.8
45	Covered interval.	7.0
44	Similar to Unit 51.	4.2
43	Similar to Unit 62.	1.2
42	Limestone, two interbedded lithologic types; limestone medium gray, weathers light gray with a blue cast, stromatolitic micrite with some lenses and patches of fine to medium clastic material, in bands 1 to 2 inches thick separated by semi-planar light gray dolomite bands $\frac{1}{16}$ to ⅛ inch thick, all of which yield a distinctive "striped" lithology. This is interbedded with medium to coarse clastic limestone beds that appear somewhat "worm-eaten". One bed contains ?*Nidulites* which is considerably below its normal stratigraphic range.	21.0

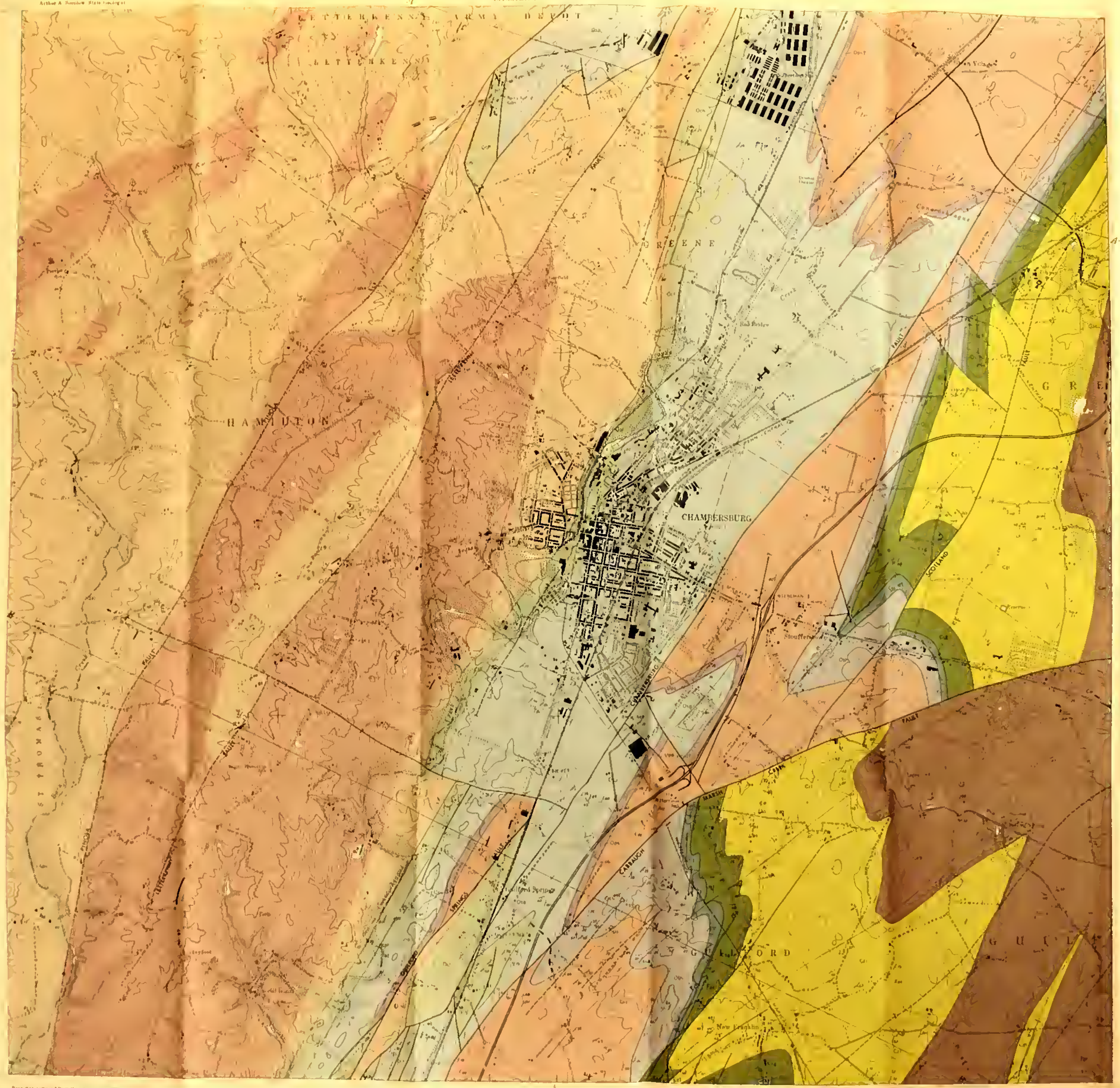
Unit		*Thickness (feet)*
41	Similar to Unit 59.	1.1
40	Limestone, algal micrite, with wispy dolomite laminae to bands, "striped" appearance, poorly exposed.	16.0
39	Limestone, algal micrite (vaughanite), in beds 1 to 1½ feet thick.	8.0
38	Interlaminated limestone and dolomite, limestone is medium gray with a blue cast and dolomite is medium gray buff; lamination is on hairline scale and shows current structures and locally very fine intraformational conglomerate.	1.2
37	Similar to Unit 42; 50 percent exposure.	28.0
36	Stromatolitic limestone, medium dark gray, weathers light gray with a blue cast, micrite, with sparse wispy dolomitic laminations.	3.0
35	Interbanded limestone and dolomite; limestone is gray with a blue cast and in bands 2 to 4 inches thick; in part clastic with *Tetradium* and other fossils; dolomite is in bands ¼ to 1 inch thick and buff colored.	3.0
34	Covered interval.	54.0
33	Similar to Unit 62.	10.0
31	Limestone, light dark gray weathers light gray with a blue cast, algal micrite with some lenses and patches of fine to medium clastic material; in bands 1 to 2 inches thick separated by semi-planar light gray dolomite bands 1/16 to ⅛ inch thick; form a distinctive "striped" rock.	4.0
30	Interbanded limestone and dolomite with some bands showing internal lamination; limestone is medium to coarsely clastic with burrow structures and mud cracks.	1.0
29	Similar to Unit 38, but with some 6 inch bands of clastic limestone and colonies of *Tetradium*.	18.0
28	Similar to Unit 62.	3.0
27	Similar to Unit 38.	7.0
26	Similar to Unit 62.	1.2
25	Similar to Unit 38.	16.0
24	Covered interval.	12.0
23	Limestone, dark gray, weathers light gray with a blue cast, micritic to semimicritic, with 30 percent muddy gray dolomite bands and irregular burrows and mottlings forming a complex network in places.	2.0
22	Covered interval.	18.0
21	Interbanded limestone and dolomite; limestone is medium dark gray, weathers medium gray with a blue cast, very finely to medium grained clastic in a semimicritic matrix, fossiliferous in part, in bands 1 to 2 inches thick; with 15 percent bright to grayish yellowish buff dolomitic bands ¼ to ½ inch thick, quite planar, they do not weather in relief.	8.0
20	Stromatolitic limestone, medium dark gray, weathers light gray, algal micrite in bands 1 to 3 inches thick but in a few places thickens and forms stromatolite head 6 inches high; with 1/16 to ⅛ planar dolomitic bands.	21.0
19	Covered interval.	37.0
18	Similar to Unit 20.	1.0
17	Covered interval.	19.0
16	Similar to Unit 20.	3.0
15	Covered interval.	8.0

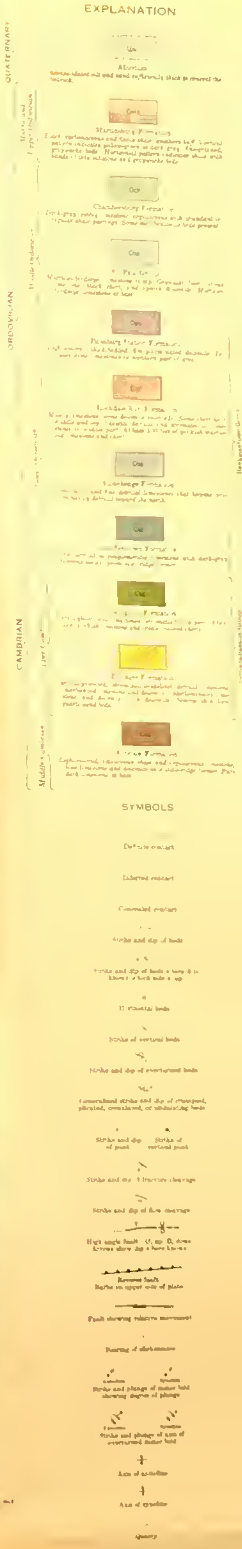
Unit		*Thickness (feet)*
14	Limestone, medium dark gray, weathers medium gray, semi-micritic with wispy dolomite laminations; some 3-inch thick bands yellow buff dolomite with bioturbate features, also a few ¼ inch dolomite clasts in the limestone.	1.0
13	Covered interval.	50.0
12	Limestone, medium dark gray, weathers dark gray, semimicritic; with semiplanar, medium gray dolomitic bands with dark cast, ⅛ to ¼ inch thick, spaced at 2 inches.	2.0
11	Covered interval.	28.0
10	Limestone, gray, composed of shell fragments and clastic grains; in bands 2 to 3 inches thick separated by wispy dolomitic laminations.	3.0
9	Similar to Unit 20.	16.0
8	Covered interval.	36.0
7	Similar to Unit 14, but with black chert nodules 1 by 8 inches, parallel to bedding.	4.0
6	Covered interval.	6.0
5	Limestone, medium gray, weathers dark gray, with abundant planar gray dolomite laminae with dark cast, ⅛ to ¼ inch thick; with trace of fossils and patches very fine clastic material.	2.0
4	Covered interval.	14.0
3	Similar to Unit 5.	5.0
2	Covered interval.	24.0
1	Similar to Unit 5, but lacking clastic material.	2.0

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

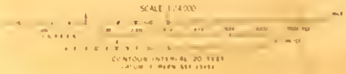
Atlas A119ab, Plate 1

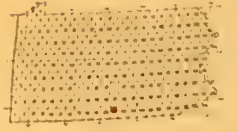


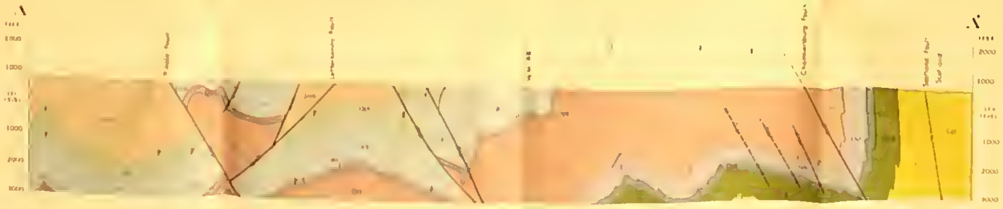


GEOLOGIC MAP OF NORTHEASTERN FRANKLIN COUNTY, PENNSYLVANIA CHAMBERSBURG AND PART OF SCOTLAND QUADRANGLE'S

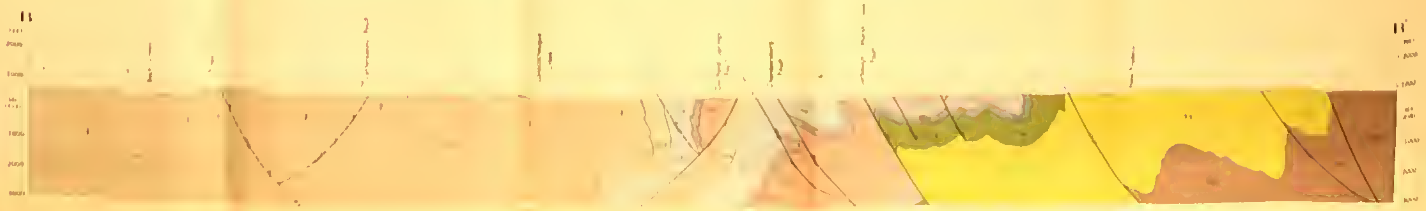
BY
SAMUEL I. ROOT
1971







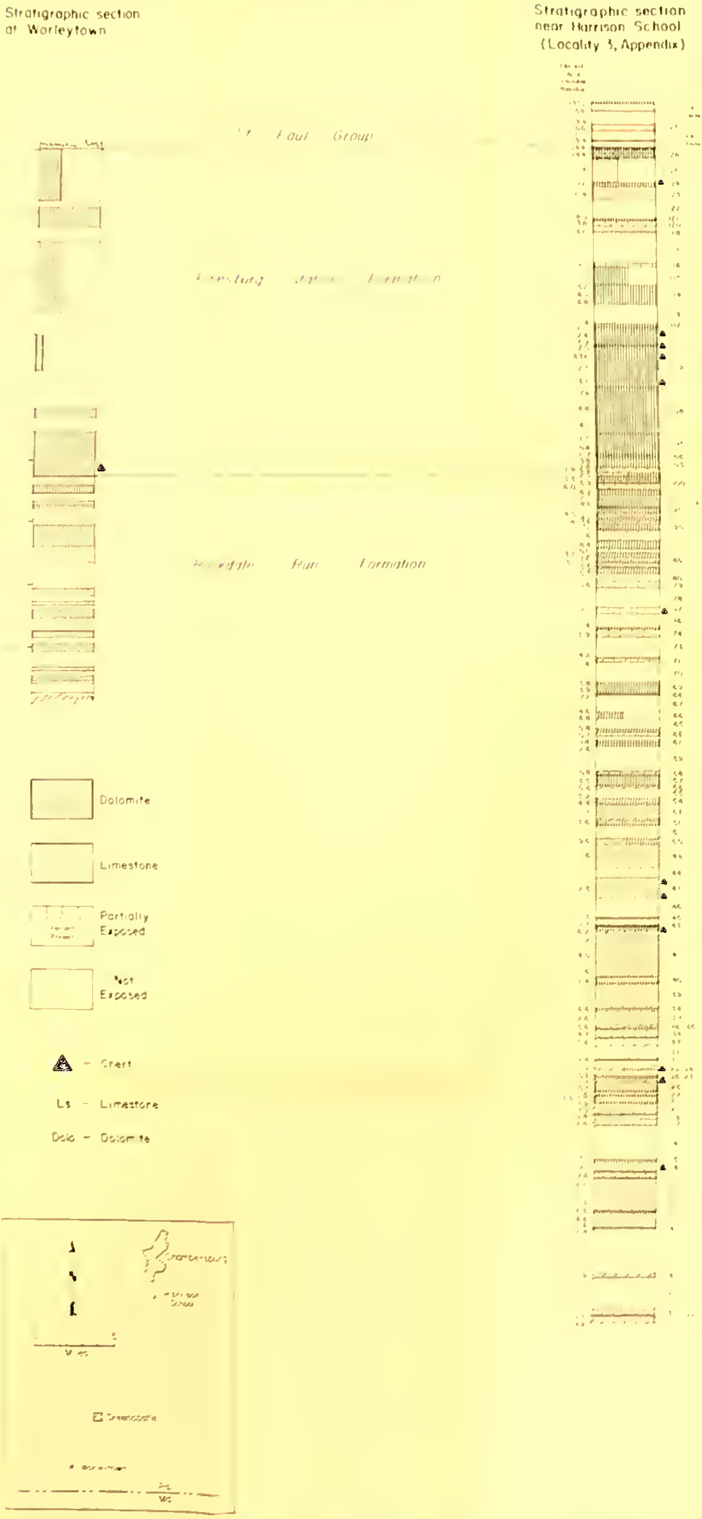
CROSS SECTIONS



TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

Atlas A119ab Plate 2


Stratigraphic section at Worleytown

Stratigraphic section near Harrison School (Locality 3, Appendix)

PLATE 2. CORRELATION AND COMPOSITION OF PINESBURG STATION FORMATION, EASTERN FRANKLIN COUNTY, PENNSYLVANIA